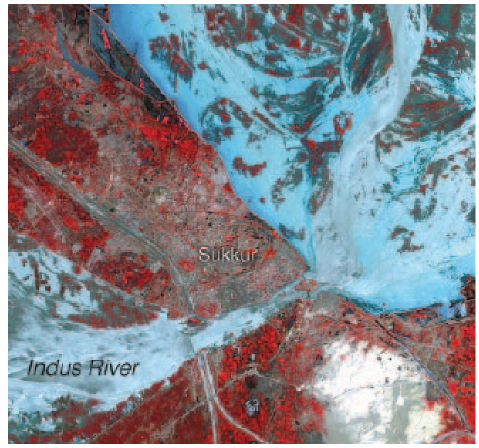
National Aeronautics and
Space Administration

GODDARD SPACE FLIGHT CENTER'S EARTH SCIENCES DIVISION

Strategic Plan / Annual Report

January 2011

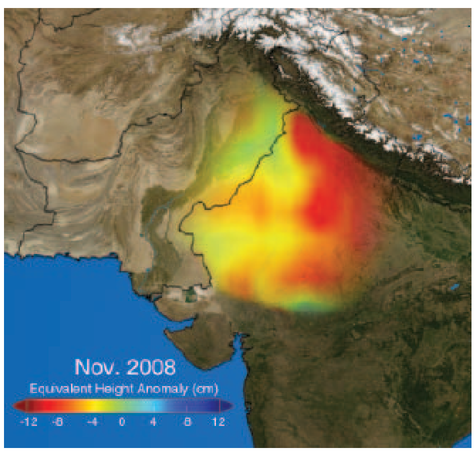
IceBridge



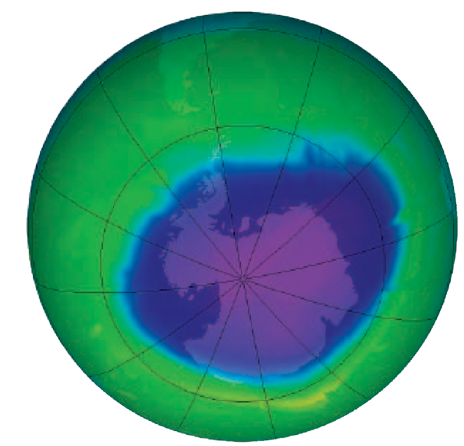
Floods in Pakistan

Our Mission

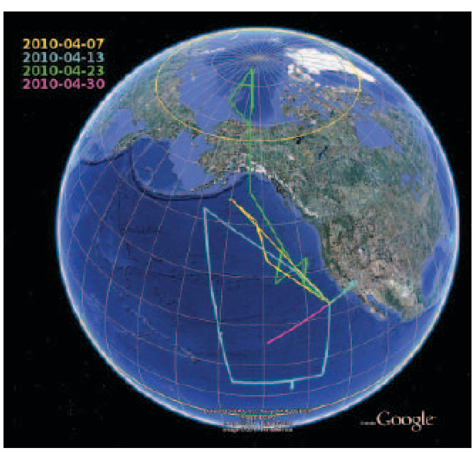
"To Improve Life on Earth and to Enable Space Exploration through the Use of Space-Based Observations"



India's Groundwater

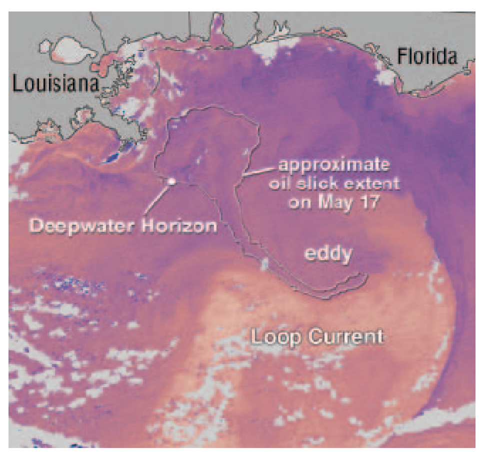


2010 Ozone Hole Maximum



GloPac Flights

Global Hawk



Gulf Oil Spill

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Preface

The national and international issues surrounding climate change make this a particularly interesting time for the Earth Sciences Division (ESD) at the Goddard Space Flight Center (GSFC). The National Research Council (NRC) report, *Informing an Effective Response to Climate Change (2010),* notes that although the

> *"...demand for information to support climate-related decisions has grown rapidly as people, organizations, and governments have moved ahead with plans and actions to reduce greenhouse gas emissions and to adapt to the impacts of climate change ... the nation lacks comprehensive, robust, and credible information systems to inform climate choices and evaluate their effectiveness."*

The many problems that surround climate change mitigation transcend the national arena, with developing countries understandably demanding assistance and compensation from the large and more highly developed greenhouse gas emitters, as all the countries try to deal with their many internal problems, of which the potential for uncomfortable climate change impacts can easily seem to be only a distant threat.

NASA's Earth sciences research program provides significant capabilities to address the increasingly pressing need for credible climate change information systems. Together with our partner agencies, including National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey, and others, NASA provides a robust and growing spectrum of definitive measurements, datasets, analyses, and scientific research on climate change. This research directly addresses human causation, and provides substantial understandings and warnings of potential human impacts. In that sense, while the NRC quote (above) significantly underestimates where we are in the our measurements and understandings of climate change, it very correctly emphasizes the pressing need for actions that will significantly improve our understanding of climate change science and the linkages to policy and implementations.

The future will provide increasing calls from the policy and economic sectors to have significantly improved application of our measurements, our scientific knowledge, and our forecasts of climate change to meet their many needs. These calls can be expected to push our climate research activities well beyond the comfort level of the typical scientific debate in peer-reviewed literature. Indeed, this is already happening. NASA Earth Sciences welcomes this.

NASA is already addressing many aspects of these new requirements. Recently, an agency-wide Carbon Measurement Office has been formed located at GSFC as part of the North American Carbon Program Office. There is also an emphasis on carbon measurements from satellites including Orbiting Carbon Observatory (OCO)-2, -3, and Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS), plus continued NASA biospheric measurements on land and at sea. Within the GSFC Earth Sciences Division, our research activities include the wide spectrum of climate change measurements, from sea ice to ice sheets and glaciers, snow pack, precipitation, runoff, biospheric health, ecosystem movement, atmospheric chemistry, aerosols and their interaction with clouds, and radiation. There are also massive efforts underway with data archival and distribution, the assimilation of data into weather and climate models, as well as regional to global climate modeling on all time scales. To this, we add exemplary science applications and public engagement programs that provide famine forecasts, world-wide flood and wildfire mapping, biospheric health analyses, science data delivery to museums around the country, education outreach support, and more.

As we move forward, we will continue to sharpen our focus on the science, and to improve our response to national and international needs for data, for data analysis techniques, and for accurate modeling of future climate change. And while we do this we also will learn even more about how to step beyond the realms of science, and to move effectively into the halls of the public, the schools and other public forums, and to more effectively disseminate our observations, knowledge, and forecasts to meet public needs.

Peter H. Hildebrand

Director of the Earth Sciences Division

Part I

The Earth Sciences Division

1. Philosophy

As we carry out our work in the Earth Sciences Division, we strive to honor the following values:

Individual Well-being

Personal Freedom

Individuals are encouraged to express their views and to offer diverging opinions. This freedom promotes a sense of openness and responsibility. Science thrives on hard work, thought, insight, and the development of knowledge, but it also flourishes best in an atmosphere of debate and discussion.

Programmatic and Research Balance

Our Division includes large programs, many large satellite missions, and observational field campaigns, all of which require the cooperative and collaborative efforts of many scientists. We aim to ensure an appropriate balance between our scientists' responsibilities for carefully leading and managing these large projects, and the need for them to maintain an active individual research agenda. This balance allows members of the Division to continuously improve their scientific credentials.

Research Quality

The Division places high importance on promoting and measuring quality in its scientific research. We strive to assure high quality through peer-review funding processes. The overall quality of our scientific efforts is evaluated periodically by committees of advisors from the external scientific community, such as the Global Modeling and Assimilation Office (GMAO) Advisory Board and the Sciences and Exploration Directorate Visiting Committee.

Scientific Partnerships

Synergy between Science and Technology

The Division aims to increase its interaction with the Applied Engineering and Technology Directorate (AETD) through the formation of joint teams to develop new technologies and engineering solutions to address scientific questions. GSFC offers enormous opportunities for synergy between engineering and scientific expertise. Experimental activities are spread across the Division to foster communication and to maximize the direct application of technology to attain scientific goals. Healthy collaboration between the Center's scientists and engineers is vital to success in the competitive research environment in which we operate.

Interaction with Other Scientific Groups

Successful implementation of the Division's mission depends on collaboration with the academic community, with other NASA Centers and Federal laboratories, and with foreign agencies. Chapter 5 discusses some of these relationships more fully. The Division has Memoranda of Understanding with a number of universities for cooperative science programs, and we have close ties with universities in Maryland through three centers: Goddard Earth Science and Technology (GEST) Center at the University of Maryland, Baltimore County (UMBC); the Joint Center for Earth Systems Technology (JCET), also at UMBC; and the Earth System Science Interdisciplinary Center (ESSIC), at the University of Maryland College Park. The Division also has a close relationship with Howard University.

Support for Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers—the project manager and the project scientist—who are the principal leaders of project management and project science, respectively.

The project scientist must provide continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Taking on the responsibilities of a project scientist provides a unique opportunity for Division staff to obtain significant scientific management experience. Typically, the Division invites candidates from the senior ranks to fill these roles.

Education and Public Engagement

The Earth Sciences Division maintains an active Education and Public Engagement (EPE) effort. Here, the word "engagement" is used in place of "outreach" to recognize the Division's efforts to create a closer connection between its staff and various public audiences. This diverse effort includes EPE support for the Division's many individual missions, but also includes formal and informal educational activities that link to educational institutions, communities, and museums across the country. These EPE activities are summarized in Chapter 11, and provide ESD staff with broad opportunities to interact with the general public, and vice versa.

Through these activities, the Division works to raise the public's awareness of Earth system science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers. The Division has close collaborations with the GSFC Offices of Public Affairs and Education.

Human Resources

The Division is committed to addressing the demographic imbalances that exist today in the atmospheric and space sciences. We must address these imbalances for our field to enjoy the full benefit of the entire Nation's talent. To this end, the Division always seeks qualified women and underrepresented ethnic groups when hiring new scientists and technologists.

Opportunities for the Commercial Sector

The contributions of the commercial sector in pursuing our goals is vital. To this end, the Division fully supports government/industry partnerships, Small Business Innovative Research (SBIR), and technology transfer activities.

2. The NASA Vision and Mission

The definition of the NASA vision, mission, scientific and application goals, and attendant space missions is the responsibility of NASA Headquarters. NASA's strategic goal for Earth Sciences is to *"Advance Earth System Science to meet the challenges of climate and environmental change."*

Addressing this strategic goal is based on addressing the fundamental question: "How is the Earth changing and what are the consequences for life on Earth?"

In order to address this goal, these component questions must be addressed:

- How is the global Earth system changing?
- What are the sources of change in the Earth system and their magnitudes and trends?
- How will the Earth system change in the future?
- How can Earth system science improve mitigation of and adaptation to global change?

To achieve the Earth sciences goal, the Science Mission Directorate (SMD) at NASA Headquarters has identified six interdisciplinary Science Focus areas:

- Atmospheric Composition
- Carbon Cycle and Ecosystems
- Climate Variability and Change
- Earth Surface and Interior
- Water and Energy Cycle
- Weather

NASA missions and associated research have many applications to societal needs. NASA Headquarters has identified nine societal benefit areas consistent with the U.S. Group on Earth Observations (US GEO) themes:

- Agriculture
- Climate
- Disasters
- Ecosystems
- Energy
- Health, including Air Quality
- Oceans
- Water Resources
- Weather

For the near future, the NASA Headquarters Applied Sciences program plans to emphasize the following themes:

- Water
- Health and Air Quality
- Ecological Forecasting
- Disasters

For more details on the Applied Sciences program, refer to Chapter 10.

NASA brings its unique vantage point of space observations to deal with the major challenge of our time of understanding human influence on climate, evolution, and predicting its impact on society. By providing substantial assets that include satellite, aircraft, instruments, and people, NASA makes major contributions to the national and international strategic Earth science goals as expressed in the report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* 2007, hereinafter referred to as the National Research Council (NRC) Decadal Survey, the *Intergovernmental Panel on Climate Change (IPCC)* 2007, and the *U.S. Climate Change Science Program (CCSP)* Report 2008.

3. GSFC's Support of National Needs for Earth System Science

The GSFC Earth Sciences Division's (ESD's) unique contribution to the advancement of Earth system science is partly the result of its long history of using the vantage point of space, and partly the result of the critical mass of scientists and engineers working across the full range of disciplines that cover the atmosphere, the biosphere, the cryosphere, the hydrosphere, and the solid Earth. The GSFC environment, where scientists, engineers, and managers all work cooperatively, provides unique opportunities for synergistic interactions to implement NASA's plans.

Specifically, ESD scientists participate in each step of the process described below, performing scientific work in collaboration with engineers, managers and information technology experts, both within NASA, and with the community:

From Science Requirements to New Missions:

1. Defining new scientific questions;
2. Identifying critical new measurements;
3. Conceiving, formulating, designing, implementing, and participating in day-to-day operations and management of satellite missions (Project Scientist Function);
4. Developing the instrument technology needed for new observations;
5. Planning and managing experimental field campaigns that validate satellite data and improve our knowledge of the underlying processes;

Creation and Distribution of Data Sets:

6. Developing algorithms to create data sets;
7. Developing models to create and interpret data sets;
8. Developing and operating data processing, archives, and distribution systems that facilitate access to and use of NASA science data;

Optimizing the Use of Satellite Data:

9. Developing models and data assimilation techniques to optimize the use of satellite data in weather and climate forecasting;
10. Developing techniques to optimize instrument design and impact on forecasting capabilities;
11. Analyzing data and models to understand the underlying processes;

Applications:

12. Leveraging NASA Earth Science research results to develop applications and to transition these to operational use for the benefit of society;

Communication and Education:

13. Communicating science results for decision makers;
14. Contributing to the scientific literacy of the general public.

Steps (1) and (2): ESD scientists work with colleagues at universities, other government agencies, NASA Headquarters, and NASA Centers to formulate the scientific objectives for the Agency.

Steps (3) and (4): Developing instruments and designing missions are core functions of the Center. NASA GSFC's strengths are the technology base for space remote sensing and in-situ remote sensing measurement capabilities, and the science base for technical development. GSFC scientists and engineers work together in developing new technologies and in developing concepts and designs for instrument systems for orbital and sub-orbital missions. GSFC project scientists provide scientific guidance to project managers while acting as the interface among the instrument principal investigators (PIs), NASA Headquarters, and the scientific community at-large.

Step (5): ESD plans and manages the post-launch field validation campaigns that support data validation and calibration, and the development of data analysis algorithms. Remote sensing observations, such as those from satellites, require careful calibration and validation. These activities provide the factual basis for proving that the advertised estimates of measurement precision and uncertainty are accurate and believable. Intense validation campaigns take place shortly after a satellite is commissioned, but validation activities continue over the course of the mission to ensure that instrumental changes are understood. Validation activities usually involve measurements by ground-based facilities, aircraft, rockets, or balloons during satellite overflights. In coordination with NASA Headquarters and other NASA Centers, ESD scientists develop validation plans and lead validation missions.

Step (6): Measurement data sets are developed by teams of instrument algorithm specialists, who work across successive missions to create the long-term, highly calibrated data sets that are needed to study the Earth's climate change and variability. ESD scientists have proven most effective at the task of converting observed signals from space-based instruments into the desired physical quantities. Data reanalysis activities in the United States and Europe have shown that inconsistencies in data quality are a large source of uncertainty in the climate record. Some inconsistencies can be traced to changes in sensor calibration, to sensor degradation, to algorithm changes, and to changes in instrumentation technologies in successive missions that are designed to continue important measurements over multiple mission lifetimes. Developing these long-term data records—with high enough quality to detect Earth system changes—is an important activity within ESD.

Step (7): Numerical modeling and data assimilation provide the only tools that address the prediction and process definition questions of the NASA Earth science research agenda. Models summarize the theoretical underpinnings of our understanding of the Earth-Sun system, integrating across the timescales and research themes. Data assimilation provides a rigorous method for bringing the observations and models together in a systematic way that balances the information from different sensors and platforms. It also provides information that has not or cannot be observed. Assimilation requires core competencies in all aspects of Earth system science. ESD scientists generate assimilation products as input to NASA instrument team algorithms, as a synthesis of NASA observations with the other observations in the global observing system, and as an historical reanalysis of Earth's climate for scientific analysis.

Step (8): Data and information management systems are a critical component to ensure the availability, accessibility, and quality of mission and research science data products. Science leadership, coupled with technical expertise in information science, information technology, computing engineering, and in specific scientific disciplines, is required to make system design and operation decisions that anticipate and address scientific insights and priorities. Having in-house expertise in these areas reduces data system start-up cost/risk, and enables data system evolution to address changing science requirements and priorities.

Steps (9), (10), and (11): The utility of satellite data, assimilation products, and global prediction models is not fully realized until they can be combined to further our basic understanding of the Earth system. Satellite data, alone or in combination with assimilation products, must be analyzed to derive information about the modes of variability of the Earth system and the interactions between the climate processes and environmental parameters that control the various feedback loops in the system. The knowledge gained is then implemented in the models via improved parameterizations to enhance prediction capabilities. Since many forced and unforced influences may operate simultaneously, innovative approaches must be pursued in developing models and data assimilation techniques, in designing new instruments, in optimizing observational platforms, and ultimately in comparing large data sets and models. As the home to the development of models and assimilation techniques and the production of assimilation products, ESD scientists are leaders in both global modeling and data assimilation. Among their many activities, they evaluate new methodologies for assimilating data from specific observing systems, and they aid in the design of new observing systems by performing what are known as Observing System Simulation Experiments (OSSEs).

Step (12): Progress in Earth system science results in many applications that benefit society. For example, water resources are a serious issue for the foreseeable future. NASA observations and models have played a critical role in understanding and globally managing this finite resource. The impact of climate change is likely to bring water- and weather-related societal issues—such as more frequent and severe floods, drought, and public health problems. Additionally, climate change and human population growth can be expected to put increased pressure on the provision of food as well as ecological diversity and sustainability. ESD scientists are fully engaged in providing NASA's space-based observations and predictions to the end users to help address these scenarios. The application of our data and knowledge to meet the needs of society is a high-priority task for the Division.

Step (13): Earth system science has many applications with substantial societal benefits. Policy makers' decisions are important for the well-being of the environment and have substantial impact on our economy. Many of these decisions are the result of progress in our science. The wisdom of these decisions depends on the accuracy of the information received by the policy makers. We believe that scientists in the Division have the responsibility to communicate in a dispassionate and objective way the results of our scientific investigations to policy makers through official channels as well as to private citizens.

Step (14): The ESD carefully considers its responsibility to contribute to the scientific literacy of the general public. To this end, scientists in the Division actively participate in NASA's efforts to serve the formal and informal education communities at all levels by supporting a number of student programs spanning the full range of the educational spectrum, and by enabling and empowering our communication partners, e.g., museums, science centers, and media providers.

We view our expertise as a national resource that goes far beyond scientists doing only fundamental research in isolation. Our Division generally deals with large projects that require the long-term sustained, collaborative efforts of many scientists and engineers. Indeed, large projects, particularly those involving conceptualization and implementation of instrumentation systems, and the long-term delivery of carefully calibrated data sets, are what distinguish the research at federal laboratories from that at universities. The associated interaction is taking place to a degree that is unprecedented in academia or elsewhere, because we at GSFC have a critical mass of scientists across a wide range of disciplines.

4. GSFC Earth Sciences Division's Mission and Goals

There are three overarching Earth science questions:

- **How does the Earth work?**
  The Earth is a dynamic planet with a complex system of interacting elements: the atmosphere, the biosphere, the cryosphere, the hydrosphere, and the solid portion of Earth's surface. NASA explores the fundamental nature and interactions of these elements. By so doing, we begin to understand how our planet works. Moreover, understanding our own living planet informs NASA's search for life elsewhere.

- **How is the Earth changing, and how can we expect it to change in the future?**
  The 4.5-billion-year history of the planet Earth is marked by tumultuous change, the causes of which are only partially understood. NASA seeks to discover what natural and man-made forces are driving today's changes, why they act as they do, and how those forces may alter Earth's environment.

- **How does our changing environment affect life on Earth?**
  Life on Earth is influenced and shaped by the environment on Earth. NASA seeks to understand how different types of change affect life and society. Our ability to understand and anticipate the consequences of change will ultimately adapt to and thrive under changing climatic conditions.

These questions are naturally linked. The processes involved are global. The answers rely on observations producing long-term data sets, their analysis, and modeling. Space observations have provided the essential global view since the mid-1970s. The third question involves prediction, the true test of our understanding, as well as our role in communicating our results to decision makers. The Division conducts a broad theoretical and experimental research program to answer these questions.

Mission, Vision, and Goals

The mission of the Earth Sciences Division is to develop an improved understanding of Earth's climate, to address key aspects of the energy, carbon, and water cycles and how they interact to support life on Earth, and to communicate our scientific results to the public and to national leaders through education and public engagement.

The vision of the Earth Sciences Division is that with appropriate partnerships, we can accomplish what others cannot, to observe, understand and explain Earth's climate, how it is changing, and how it affects life on Earth.

The long-term strategic goals of the Earth Sciences Division are to:

- Implement the NRC Decadal Survey missions,
- Implement the upcoming operational Earth science space missions including the Joint Polar Satellite System (JPSS) (NOAA), and Landsat (U.S. Geological Survey),
- Provide cutting-edge weather and climate forecast models and the needed high performance computing, and
- Promulgate the data and knowledge we gather through a vigorous education and public engagement program.

Our mission and goals provide the strategic foundation for ESD activities. These assets are programmatically managed by the Earth Science Division at NASA Headquarters, but are conceived, designed, implemented, and operationally managed at the various NASA Centers, in collaboration with the academic community and the private sector.

The Goddard Space Flight Center has a broad mix of resources for conceiving and flying satellite missions. GSFC has well-recognized strengths in flight dynamics, engineering, scientific management, data production, and data distribution. GSFC has developed and managed a wide range of missions, from large multi-instrument platforms like the Earth Observing

System (EOS) Terra, Aqua, and Aura satellites, to small single-instrument satellites like the Earth Probe Total Ozone Mapping Spectrometer (TOMS) and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). GSFC has built and managed the series of Landsat missions that have monitored land use and land coverage since 1972, and is now building the Landsat Data Continuity Mission (LDCM). A large number of ESD civil servants function as principal investigators and project scientists for major satellite efforts. A list of project scientists and deputy project scientists is provided in Appendix C.

In order for NASA scientists to function effectively in support of NASA missions, they must maintain their own scientific efforts and have their research vetted through the peer-reviewed literature. They must continue to participate in and help lead the nation's science programs. First-rate science missions require first-rate scientists and engineers for their conception, design, and implementation. First-rate scientists must be recruited, nurtured, and developed over a number of years to maintain the highest quality in the entire work force.

5. Inside GSFC's Earth Sciences Division

5.1 What the Earth Sciences Division Does

The purview of the Earth Sciences Division includes:

- The atmosphere
- The biosphere
- The cryosphere
- The hydrosphere

Interactions between these components takes place at time scales ranging from minutes in cloud evolution, to months to years for short-term climate variability, and decades to centuries for climate variability and change.

ESD scientists do research in all components of the Earth system, (except the solid Earth), they are at the forefront of interdisciplinary science. Increasingly, we see our planet as a system of systems, with the most exciting discoveries occurring at the interfaces between traditional disciplines.

Major science areas addressed in ESD are shown in Table 5.1. For each focus area the table also identifies instruments or space missions presently flying or in development; the latter listed in Appendix A, Table A.1. Those Recommended by the NRC Decadal Survey are listed in Appendix A, Table A.2. The last column has the corresponding NASA Headquarters-generated Focus Areas.

Table 5.1. ESD Science Focus Areas

Focus Area	Science Questions	Instruments/ Space Missions	NASA Headquarters Focus Areas
Atmospheric Aerosols	• How do aerosols affect regional and climate? • How do aerosols affect the Earth's heat balance? • How do aerosols affect cloud and precipitation? • How do aerosols affect ecosystems? • How do aerosols affect health?	MODIS, MISR, OMI, ICESat, CALIPSO, EO-1, Glory, NPP, JPSS, ACE, GEOCAPE	Atmospheric Composition
Atmospheric Chemistry	• How do anthropogenic activities impact atmospheric pollution at regional and global scales? • What is the impact of long-range transport of pollutants on local air quality? • How will climate change impact local air quality and how will changes in atmospheric composition influence climate change? • How will the stratospheric cooling associated with climate change impact the spatial extent and recovery of the ozone layer and the Antarctic ozone hole? • Is stratospheric ozone recovering in a manner expected from theoretical predictions? • How well can we predict atmospheric chemical impacts on ozone and climate?	SBUV series, Aura, MOPITT, AIRS, NPP, JPSS, ACE, GEOCAPE, GACM	Atmospheric Composition

Table 5.1. (continued) ESD Science Focus Areas

Focus Area	Science Questions	Instruments/ Space Missions	NASA Headquarters Focus Areas
Atmospheric Water Cycle	• What are the causes of water cycle variations? • How do clouds, water vapor, and precipitation processes affect regional-to-global weather and climate? • What changes to the atmospheric water cycle are expected in a warmer global environment, especially events with high impact on society such as hurricanes, floods, drought, and forest fires? • How can we use satellite measurements to better understand the physical processes of the atmospheric water cycle and to provide better representation of these processes in global climate and weather models?	AMSR-E, TRMM, GPM, NPP, JPSS, SMAP, ACE, PATH, 3D-Winds	Water and Energy Cycle

Carbon Cycle and Ecosystems	• How are the Earth's carbon cycle and ecosystem changing?
	• How will climate change influence carbon cycle, ecosystem sustainability, and biodiversity?
	• What needs to be done:
	  • Document terrestrial and marine ecosystems.
	  • Document land cover and use changes.
	  • Quantify global productivity, biomass, and carbon fluxes.
	  • Improve ecological forecasting and climate change predictions.
		Landsat, AVHRR, SeaWiFS, MODIS, ICESat, EO-1, NPP, LDCM, SMAP, ICESat II, DESDynI, ASCENDS, GEOCAPE, ACE, LIST, HyspIRI	Carbon Cycle and Ecosystems

Climate Modeling and Analysis	• What is driving climate change? • How does the Earth system respond to changes in climate, and what are the associated feedbacks? • What are the impacts of climate change? • What can humans do to alter the magnitude and direction of climate change?	Glory, GPM, NPP, Landsat, all recommended missions in the NRC Decadal Survey	Climate Variability and Change
Oceanography	• How does the ocean circulation contribute and react to changes in the global climate system? • What is the character and variability of the global ocean biology that is detectable through changes in ocean color? • What are the feedbacks between surface-layer dynamics, biology, and optical properties?	SeaWiFS, MODIS, Landsat, Aquarius, SWOT, PACE, ACE, GEOCAPE	Climate Variability and Change
Polar Climate Change	• How will changing ice cover contribute to future sea level and over what time scales? • Will there be catastrophic collapse of the major ice sheets? • What will be the influence of changes in land ice on the climate system, the water cycle, and the biosphere? • How will changes in sea ice affect climate and climate processes?	ICESat, MODIS, SMMR, SSM/I, Landsat, ICESat II, DESDynI, LIST, GRACE II	Climate Variability and Change

Table 5.1. (continued) ESD Science Focus Areas

Focus Area	Science Questions	Instruments/ Space Missions	NASA Headquarters Focus Areas
Terrestrial Water Cycle	• What are the causes of water cycle variations? • Are variations in the global and regional water cycle predictable? • What is the impact of variations of snowmelt runoff on the availability of fresh water? • How are water and biological cycles linked?	Nimbus 7/ SMMR, Landsat, SSM/I, AVHRR, GOES, GRACE, MODIS, AMSR-E, AIRS, GPM, MAP, SWOT, ACE, GRACE II, SCLP	Water and Energy Cycle

Weather and Short-term Climate	• What needs to be done here:
	  • Interpret the information that the observations provide regarding the variations in our environment.
	  • Make consistent estimates of the state of the Earth system.
	  • Enhance prediction of our future environment.
	  • Enhance our understanding of the possible link between climate change, hurricanes, and severe storms.
	  • Identify the merits of existing and potential of new observations.
		GPM, SMAP, Aquarius, SCLP, JPSS, NPP, ACE, 3D-Winds, other missions suggested in the NRC Decadal Survey	Weather

NASA Earth system science results can be applied to multiple applications. Weather and climate can affect aviation, air quality, health, transportation, agriculture, fisheries, water, energy, construction, tourism, and many other sectors of the economy. Even modest advances in forecast skill lead to huge economic gains.

ESD members make contributions to each of the nine primary societal benefit areas listed in Chapter 2. The types of contributions they make are included in Table 10.1 in Chapter 10, which also identifies our partners and the products we provide them. The interaction with our partners often consists of a joint evaluation of the usefulness of our products, provides important information about what users need, and is an important step in the difficult process of transition from research to operations.

We measure the success of our Division by the usual metrics applied to scientific organizations of its size and breadth. Our average win rate for proposals, based on selections from the period of April 2005 to December 2010, was 41 percent. As another measure of our engagement with the community, we report in Appendix D the number of field campaigns we have led or participated in and the number of workshops we have sponsored in 2010. Appendix E shows the number of professional awards and honors bestowed on our staff.

5.2 Development and Management of Long-Term Data Sets

Earth- and space-observing satellites have been flown by NASA since the mid-1970s. One of the most major activities for our scientists is to continue the development and updating of data analysis algorithms following launch, thereby improving the quality of the data obtained from the sensors. These efforts often extend well beyond our own satellites and sensors to those launched by other organizations—both domestic and international. In this way, GSFC scientists lead the scientific community in developing a space-based understanding of the Earth and solar environments.

Over time, the collection and reprocessing of the data from these early sensors and the process of combining data from more recent sensors with older data has led to the development of what is called “long-term data sets”. The scientific community regards these long-term data sets as an important resource. For example, the column ozone data from the first backscatter ultraviolet (BUV) instrument flown on Nimbus 4 in the mid-1970s combined with the TOMS/SBUV, the NOAA SBUV-2 series, Meteor TOMS, Earth Probe (EP) TOMS, up to the recent Aura Ozone Monitoring Instrument (OMI) has provided the stratospheric community with a near continuous measure of changes in the stratospheric ozone layer. The development of satellite-based long-term data sets is complemented by data collected from ground-based networks supported by NASA, e.g., the Aerosol Robotic Network (AERONET), the Micropulse Lidar Network (MPLNET), and the Network for Detection of Atmospheric Chemical Change (NDACC).

The development of long-term satellite data sets is time-consuming, specialized work that requires knowledge of remote sensing, sensor performance, and field calibration and validation techniques, all integrated with in-depth understanding of the basic science. The development of long-term data sets from satellite systems is an appropriate function for NASA, although we expect this activity will eventually transition to NOAA for some of the Earth science data sets as the Joint Polar Satellite System (JPSS) comes online. We view the maintenance and improvement of these data sets as a serious responsibility of ESD and an important service to the community.

Some of the key data sets that ESD maintains and the sensor suites from which the data sets are derived are listed in Chapter 8.6.1.

5.3 Managing and Setting Priorities within the Earth Sciences Division

The Earth Sciences Division's strategic planning activities are supported by a process called the Earth Science Line of Business (LOB). The LOB process was instituted several years ago at GSFC in order to centralize planning—particularly mission planning—across ESD. The LOB process is designed to provide Center-level accountability within which:

- Each LOB reports on a regular basis to the Center's New Business Committee;
- Strategic goals are updated annually, including needs for Center internal investment support and staff;
- Use of internal investment funds is reviewed;
- Progress on approved projects, instrumentation development, and missions is monitored; and
- The Earth Sciences Division goes a step beyond this by using the Earth Sciences LOB as a priority-setting and review board that makes decisions concerning all major priorities, including staffing, allocation of space, and Divisional discretionary funding.

The Earth Sciences LOB team meets weekly, and consists of:

- ESD senior staff, including the associate ESD director for Mission Formulation and the ESD chief engineer;
- A lead manager/planner from the Center Strategic Planning Office who works closely with the ESD director to run the LOB;
- Several ESD scientists; and
- A representative from the Engineering Directorate.

Earth Sciences LOB Goals for Fiscal Year (FY) 2011 include:

1. Supporting of Earth Sciences NRC Decadal Survey, JPSS and Landsat missions, plus continued support of EOS- and ESSP-era missions;
2. Continuing leadership in sustained climate measurements from space missions;
3. Using Venture Class mission opportunities to advance critical Earth sciences measurements;
4. Developing critical new climate simulation capabilities including improved models and high performance computing;
5. Developing of new airborne instruments for Earth sciences; and
6. Increaseing education and public engagement activities.

NRC Decadal Survey missions refer to the 15 mission portfolio recommended by the NRC in 2006. The NRC Decadal Survey missions are separated into three time frames or Tiers. Tier 1 missions are all in formulation and will launch between 2015 and 2019. These missions include the Soil Moisture Active Passive (SMAP) mission, led by the Jet Propulsion Laboratory (JPL), with GSFC providing the key radiometer system; the Ice, Cloud, and Land Elevation Satellite (ICESat)-II mission, led by GSFC; the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission, led by Langley Research Center with GSFC providing the Reflected Solar instrument; and the Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission, led by JPL with GSFC as the lead for the Lidar platform.

The Tier II missions include the Surface Water and Ocean Topography (SWOT) mission, the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission, the Aerosol, Cloud and Ecosystem (ACE) mission, the Hyperspectral Infrared Imager (HypsIRI) and the Geostationary Coastal Ocean and Air Pollution Events (GEOCAPE) mission. The NRC Decadal Survey Tier-II missions are in pre-Formulation and will be launched no earlier than 2019 beginning with SWOT and ASCENDS. Leadership of the Tier II missions is still to be formally decided.

Tier III missions described by the NRC include the Lidar Surface Topography (LIST) mission, Snow and Cold Land Processes (SCLP) mission, Global Atmospheric Composition Mission (GACM) mission, Three Dimensional Winds (3DWinds) mission, and the Gravity Recovery and Climate Experiment (GRACE)-II mission. Tier III missions will not likely launch until the middle of the next decade (approximately 2025), therefore current support is primarily technology investment for measurement and instrument concept development.

Each of the Tier II and Tier III missions represent significant new work for GSFC; the ES LOB is working closely with ESD management and science leadership to develop plans that will maximize appropriate participation in the missions, utilizing application of GSFC's science, engineering, and project management capabilities to best meet mission needs. Mission-specific capture plans are developed by the ES LOB and supported with internal resources, including Internal Research and Development (IRAD) and Strategic Science FTEs. The ES LOB also helps to coordinate with other NASA development programs—such as the Instrument Incubator Proposal (IIP) and the Advanced Technology Initiatives Program (ATIP)—to garner support for GSFC concepts.

GSFC's ES LOB activities also address national needs for enhanced climate simulation and sustained climate measurements of the Earth from space. The NASA program of EOS satellites, (Aqua, Terra, Aura, ICESat, plus the operational GOES and POES), provide a substantial basis for documenting and understanding Earth's climate from space. GSFC will continue to provide scientific and technical leadership of critical climate measurements and missions, including implementation of the JPSS. JPSS is the restructured civilian portion of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) that will make afternoon observations as it orbits Earth. The system includes the satellites and sensors supporting civil weather and climate measurements, and a shared ground infrastructure with the Department of Defense (DOD) Weather Satellite System (DWSS). JPSS is crucial to the Nation's ability to make important weather measurements and is critical to the nation's climate monitoring and climate research activities.

In addition to space-based observations, airborne instruments, ground-based networks, and field campaigns play an essential role in the improving our understanding of the Earth's systems. They provide data to answer relevant science questions with new and unique measurements, providing high spatial and temporal resolution observations that cannot be obtained from satellite instruments, supporting calibration and validation of orbiting sensors and serving as test beds for new technologies for the next generation of Earth Sciences instrument and sensors. All told, airborne instruments help build up GSFC expertise and leadership in Earth Science, and are an essential technical and programmatic stepping-stone to winning future ES missions. ESD is committed to expanding this capability, and will continue to leverage various combinations of IRAD, SBIR, Innovative Partnerships Program (IPP), Earth Science Technology Office Advanced Component Technology (ACT) and IIP, Airborne Instrument Technology Transition (AITT), and NASA Headquarters-provided direct funding in support of GSFC activities.

The Venture Class opportunities are discussed in detail in Chapter 9.2.3

Resources Available

- The IRAD program is designed to fund new instruments or research ideas. Proposals are chosen through an internal competitive selection process. The funds are obtained through assessments levied by the Center on business coming from NASA Headquarters.

- Strategic Science full-time-equivalent (FTE) are funds that the Center invests in activities that are critical to implement the NASA agenda. Typically, these FTEs are used for scientists assigned to investigate new ideas for instruments, missions, or topics. Some FTEs are used for supporting new hires, graduate students (through the Cooperative Education Program), and civil servants who wish to spend up to one year of sabbatical time at approved academic or government institutions.

The total number of FTEs obtained by the Division to support civil servants through the above activities is included in Chapter 6.3, Figure 6.4.

5.4 Supporting Mission Planning for NASA Headquarters

The GSFC Flight Projects Directorate has established an Earth Science Projects Division (ESPD) that has three main functions:

1. To oversee the execution of missions under development, such as the Global Precipitation Measurement (GPM) Mission;
2. To carry out implementation plans for systematic missions that are in formulation, such as SMAP; and
3. To provide feasibility studies for missions recommended by the NRC Decadal Survey and not yet recommended for formulation by NASA Headquarters.

The ESPD is the equivalent of a NASA Headquarters function located at the Center, and is independent of the Center's ES LOB activities; however, ESD provides civil servant scientist support to ESPD and provides science study leads for some of the NRC Decadal Survey missions. In addition, ESD scientists are members of all but one of the science working groups for NRC Decadal Survey missions.

5.5 Partnerships with the Academic Community and Government Laboratories

Interaction with the national and international scientific community is essential, and is an integral part of the Division activities. Scientists in the academic community and in government laboratories at home and abroad are involved in our research activities, ground-based observational programs, aircraft campaigns, and satellite missions. Indeed, these programs are often jointly funded by other agencies and co-sponsored by the international community. Our data sets are created with major contributions from the community and serve as a resource for the community.

In addition to individual interactions among scientists, the Division has established research institutes with a number of universities around the country for the purpose of involving first-rate scientists in our research activities. A substantial effort is underway to encourage graduate students to interact with our scientists, use our data sets, and work with our models. More information is available in Appendix B.

5.6 Partnerships with Operational Agencies

The ESD is fully supportive of NASA Headquarters' goal of optimally exploiting satellite data for operational and application purposes. We recognize the challenge of "Crossing the Valley of Death" [*Research to Operations in Weather Satellites and Numerical Weather Prediction, National Research Council*, 2000], a term often used in industry to describe the difficulties of transitioning from research to operations. To address this challenge, we have formed the Joint Center for Satellite Data Assimilation (JCSDA) with NOAA and the Department of Defense (DOD). We recognize the importance of actively cooperating with other operational agencies and transitioning our research techniques and software into decision support tools (see Chapter 10). We make every effort to seek out and implement such cooperative activities.

The ESD is also supporting the SMD's "valley of death" challenge in another way, by trying to determine if data from operational satellites can be used for answering climate change questions. ESD is home to several measurement teams that have created long-term data sets from combined research and operational satellites (see Chapter 8.6.1). These measurement teams in ESD are preparing to extend their EOS expertise into the NPOESS Preparatory Project (NPP) and JPSS era.

An operational agreement exists between the Landsat Project Science Office (LPSO) and the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) office to support LPSO activities in Landsat characterization and calibration operations.

ESD partners with the U.S. Agency for International Development (USAID), USGS, Department of Homeland Security, U.S. Department of Agriculture (USDA), Environmental Protection Agency (EPA), DOD, the U.S. Department of Transportation (including the Federal Aviation Administration), and international organizations such as the World Bank, the United Nations, International Red Cross, and others to transition science research results to operational use.

5.7 Toward a More Diversified Workforce

As we move into the future, we are continuing to creatively adjust our workforce to more closely reflect the demographics of the population. These adjustments include components of age, gender, and racial diversity. Although the demographics of the highly educated population lag behind that of the population as a whole, there are a number of steps that are proving successful for us in adjusting the nature of our workforce. It is also important to include planning for rejuvenation of the workforce as the experienced staff retires and their positions are filled by new younger staff. The ethnic and racial distribution in the population is evolving rapidly, and the majority of the workforce will change by the middle of the century or earlier. It is important that the composition of the Division workforce changes accordingly and that we create a more inclusive environment. We have taken the following steps toward achieving a more diversified workforce:

- We work with universities, including Howard University, to attract minorities to our field.
- We run summer programs for undergraduate and graduate students to attract them to our field. Some of the students are women and minorities.
- We use the GSFC Cooperative Education Program for graduate students to attract minorities to our field.
- We have instituted a mentoring program internal to the Division to help women advance scientifically and professionally in their careers. Biweekly luncheons are organized in the Center cafeteria.
- In the last year, we have advertised as broadly as possible. We have hired 3 African-Americans and 4 women out of a total of 13 new hires.
- We are fully involved with the Directorate Diversity Team, whose function is to create a more inclusive and welcoming environment for all our employees.

6. How GSFC's Earth Sciences Division Operates

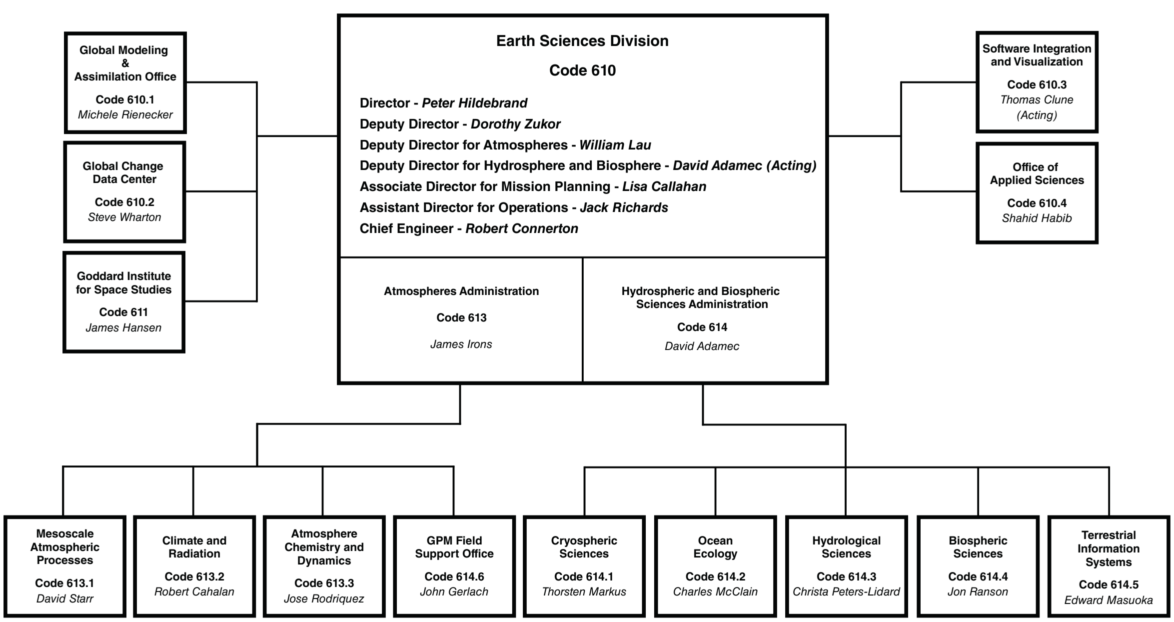
6.1 Organizational and Administrative Structure

The Earth Sciences Division is one of the four divisions of the Science and Exploration Directorate (SED). The other three are the Astrophysics Science Division, the Heliophysics Science Division, and the Solar System Exploration Division. This structure roughly mirrors the organization of NASA Headquarters.

The management structure of the Earth Sciences Division is currently undergoing revision, with the goal of improving communication between the Division Office and the 14 Branches and Offices that make up the Division. The new structure is still evolving but, as shown below, the major change that will result from this reorganization is the change in the ESD senior staff meetings, which now include all 14 organizational units, plus the formation of an ESD Executive Committee. The broader senior staff meetings were implemented in the fall of calendar year 2010, and have quickly improved communication within the Division. The existent administrative offices for the two previous laboratories, plus their staffing and administrative duties, will continue to be maintained. The Executive Committee results from naming the heads of the previous Laboratory for Atmospheres and the Hydrospheric and Biospheric Sciences Laboratory, as deputy directors of the Division, and will also include the associate director for Mission Planning, the chief engineer, and the assistant director for Operations. The directors of the Goddard Institute for Space Studies (GISS) and the Global Modeling and Assimilation Office (GMAO) will be included in the ESD Executive Committee as available.

Other organizational changes will include a realignment of the Software Integration and Visualization Office (SIVO) and a realignment of the current Field Support Office at the Wallops Flight Facility. The SIVO will become more focused and revitalized by shedding the current Scientific Visualization Studio (SVS), which will join the SED-level Computational and Information Science and Technology Office (CISTO), with some user support activities also joining CISTO, and with the balance of SIVO's high-end software engineering activities that support GISS being maintained and moved to Building 33, where the interaction with GMAO will also be improved. The current Field Support Office at Wallops will be reborn as

EARTH SCIENCES DIVISION — *Proposed Organization*



the Global Precipitation Measurement (GPM) Field Support Office, and will have a GPM-centric focus on precipitation measurements using radars, surface stations, and aircraft.

GISS and GMAO will retain their present focus on climate modeling and data assimilation, as well as their organizational reporting relationships. The Global Change Data Center (GCDC) will continue to lead highly efficient development of science data systems for product generation, data management, and distribution for the Division and the Enterprise. The Office of Applied Sciences will continue leveraging NASA science products for societal benefit by identifying potential applications of SED science discoveries, scientific observations, data analyses, and technology that could benefit other government agencies, industry, and the public.

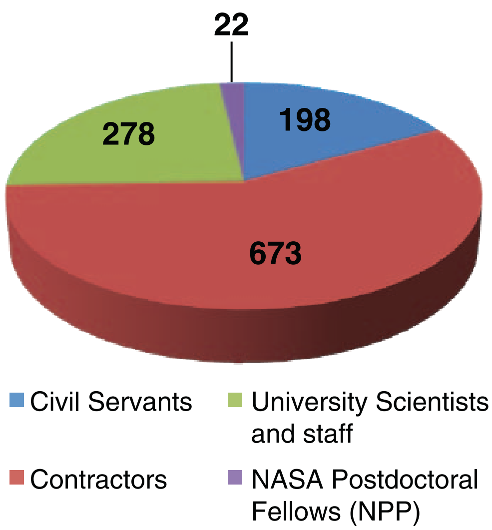


Figure 6.1 ESD Personnel Composition

6.2 Workforce Composition

The composition of the ESD workforce has evolved substantially in the last several years, in part because of the general reduction of the civil servant workforce, and in part in recognition of the scientific advantages of increasing the work done through the formation of joint institutes with universities.

The relative composition of the ESD Division is summarized in Figure 6.1.

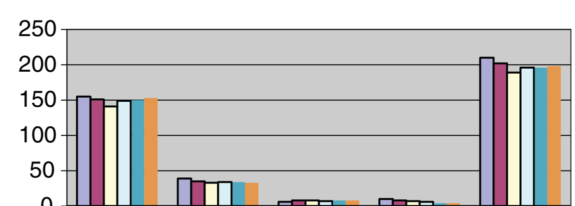
The human capital of the ESD includes:

- **Civil Servants**
  Civil servants are federal employees who are not part of the military. Civil servants are the core research staff in the ESD. This category also includes term appointments, which can have a duration of up to six years. At the end of the six years (or earlier), a decision has to be made about converting the position into a permanent one, or terminating the position. The ESD currently has 198 civil servants.

- **Scientists from Joint Centers, NASA Postdoctoral Program, etc.**
  Most of the non-civil servant scientists come from the joint centers that the ESD has established with the University of Maryland at Baltimore County (UMBC), the University of Maryland at College Park (UMCP), George Mason University in Virginia, and Columbia University in New York City. Others are NASA Postdoctoral Program (NPP) fellows: this is a program for postdoctoral fellows run by the Oak Ridge Associated Universities (formerly run by the National Research Council). Professors on sabbatical or other senior scientists in research organizations, are part of the ESD Visiting Fellows Program run by the GSFC Earth Sciences and Technology Center (GEST) at UMBC. Some of the scientists at the joint centers develop their own research activities through proposals written to various agencies including NASA, and thus serve as principal investigators who work cooperatively with the civil servants. See Appendix B.

- **Contractors**
  A major component of the work force is employed by the private sector. The contractor workforce includes technicians, programmers, information technologists, engineers, and scientists with MS and PhD degrees.

The civil servant skill distribution is described in Figure 6.2. The figure also provides information about workforce evolution from FY 2006 until the present.



	Scientists	Engineers	Prof. Admin.	Clericals	Total
FY06	155	39	6	10	210
FY07	151	35	8	8	202
FY08	141	33	8	7	189
FY09	149	34	7	6	196
FY10	150	34	8	4	196
FY11 to date	153	33	8	4	198

Figure 6.2. ESD Civil Servant Skill Distribution

6.3 Funding Sources for the Division

The funding sources for the Division are depicted in Figure 6.3

Figure 6.3 includes funds for civil servants salaries, non-civil-servant personnel, equipment, and any other activity in the Division.

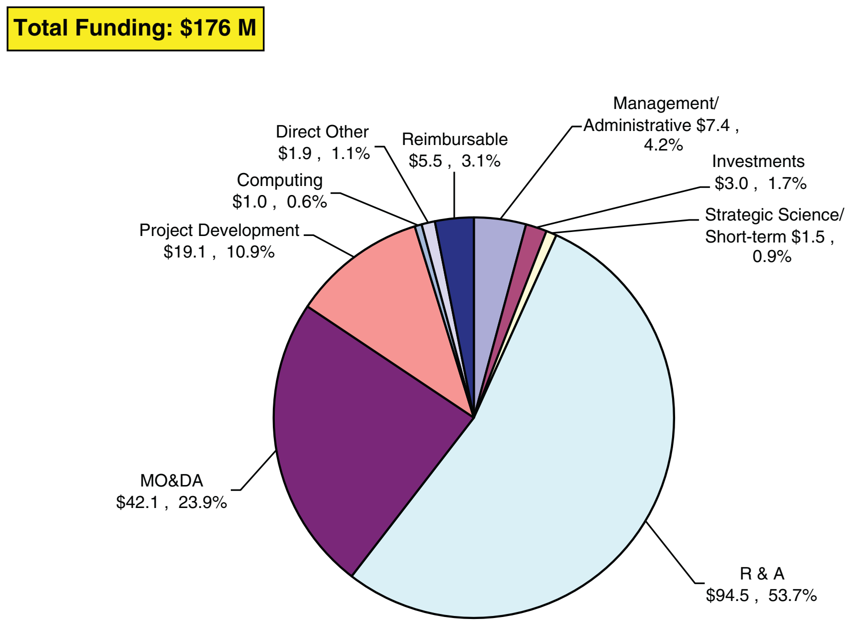


Figure 6.3. ESD Funding Summary for Fiscal Year 2010 ($M)

The funding sources for the civil servant positions are outlined in Figure 6.4.

The elements in this figure have the same meaning as for Figure 6.3.

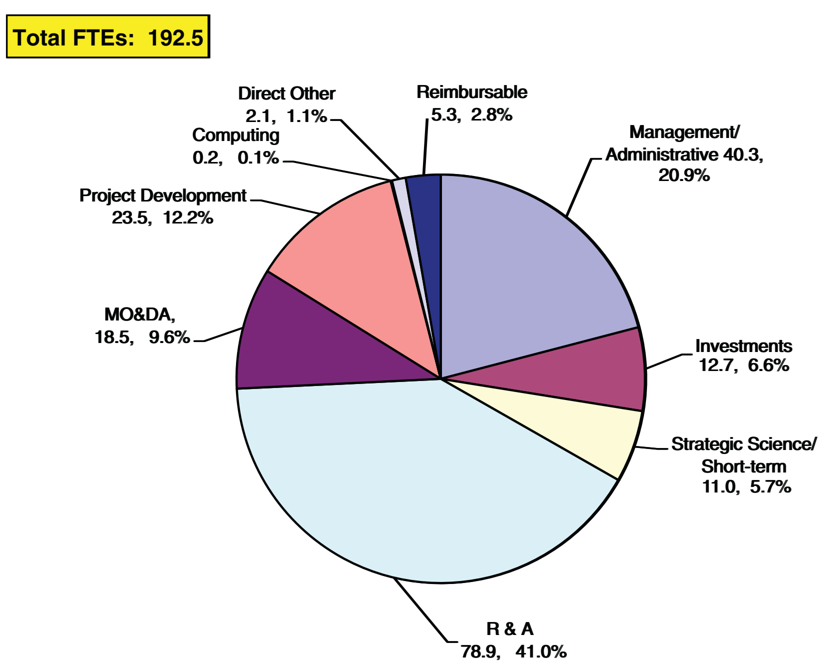


Figure 6.4. Funding Sources for Fiscal Year 2010 ESD Civil Servant Salaries (FTEs)

The following table provides more-detailed funding and civil service FTE information.

Table 6.1. Funding and Civil Service FTE Information

		Funding ($K)	FTEs
R&A			
	Research and Analysis (R&A)	87,585	71.4
	Applications	4,405	5.0
	Education & Outreach	1,349	1.7
	IIP/ACT/ATIP	1,163	0.9
MO&DA		42,099	18.5
Project Development			
	Projects	18,682	19.6
	NRC Decadal Survey	464	3.9
Management/Administrative			
	CM&O	1,800	3.9
	RDMS	5,605	36.4
Investments			
	CM&O Strategic Science	1,491	11.0
	IRAD	1,358	5.1
	B&P	828	5.1
	Cost Sharing	449	2.6
	Tech Equip	368	0
Direct Other			
	Mission Support	1,616	0.2
	Agency Community Service	321	1.7
Computing Services		1,042	0.2
Reimbursable		5,457	5.3
Totals		176,081	192.5

The FTEs chart shows that a large percentage, 47 percent, of the FTEs comes from the Research and Analysis (R&A) sources. This points to the major role that writing successful research proposals has in the Division. Indeed, the success rate of the Division scientists has been consistently high ranging in the last three years, between 39-44 percent. The relatively large percentage of R&A funds results in heavy pressure on the Division scientists, as we will further discuss in Chapter 7.

The categories have the following meaning:

- Research and Analysis (R&A) are funds received from NASA Headquarters through Research Opportunities in Space and Earth Sciences (ROSES) competition.
- Applications are activities in the area of societal benefits funded by NASA Headquarters through competition.
- Education and Outreach is largely competed.
- IIP/ATIP/ACT are NASA Headquarters technological programs which are fully competed.
- MO&DA support refers to activities directly related to the analysis of data obtained for a given mission.
- Project Development directly support a number of people involved in the management of the missions (project scientists, associate project scientists, etc.).
- NRC Decadal Survey Support consists of funds received from NASA Headquarters to study the possible implementation of NRC Decadal Survey missions. These funds are not competed.
- Center Management and Operation (CM&O) and Research and Development Multiple Support (RDMS) cover support for administrative, clerical, and managers (branch heads, laboratory chiefs, and division director), as well as some support for Education and Public Engagement and IT Security.
- Investments are funds from the Center's CM&O budget to increase our competitiveness in winning proposals.
    - CM&O Strategic Science is a program funded by GSFC to support important scientific objectives. There is some competition within the Directorate.
    - IRAD is funded by GSFC to carry out primarily technological development. These funds are competed within GSFC.
    - B&P are funds made available to civil servants to cover their time in writing proposals.
    - Cost sharing is the Center's contribution to cover a portion of civil servants salaries identified in a proposal. The program was terminated at the end of FY 2010.
    - Tech equipment is the Center's strategic contribution for purchasing new laboratory equipment or refurbishing existing laboratory equipment.
- Direct other is funds that support NASA mission EPE.
- Agency Community Service funds civil servant expertise when requested by SMD to support peer reviews, advisory groups, roadmap teams, etc. These funds are not competed.
- Computing Services is funds SIVO receives from the GSFC Computational and Information Sciences and Technology Office.
- Reimbursable is applied work that we do for other organizations. Proposals are written, but the funding is not usually the result of competition.

7. Challenges and Opportunities

In addition to the highly welcomed scientific and technological challenges, scientists in the Division face two significant management challenges: the impact of Full Cost Accounting and an aging work force. These are discussed below.

7.1 The Funding Process and Full Cost Accounting

Under so-called Full Cost Accounting (FCA) over the past several years, civil servants have been responsible for covering their salaries through proposals they write or through participation in various space mission opportunities. Consequently, they have had dual responsibilities: on one hand, they have to secure funds through competitive proposals to support their research activities (i.e., recovery of salaries for themselves, the university scientists they support, contractors, and equipment needs, etc.); on the other hand they have to actively participate in the process of bringing new instruments and missions to the Center. The pressure on the scientists brought about by FCA is unique; as FY 2011 became imminent there had been hope that scientist funding would revert to the previous approach, i.e., base funding of the civil service scientists, but with ongoing "full cost" tracking of the expenditures of civil servant time and of other expenditures. While this had been hoped for as a welcome change it was not, for a variety of reasons, implemented, and as of this writing (FY 2011), we continue to operate in the so-called FCA mode, as described above.

As shown earlier, in Figure 6.3, about 56 percent of our research activities are supported by competitive proposals to ROSES or to GSFC internal programs. The majority of this percentage, 54 percent, comes from ROSES. The civil servant PIs on these proposals have responsibility for their success, as measured by refereed publications or by working on missions and instruments for space or airplane applications. These are all important activities in implementing the NASA agenda, as well as in supporting the outside community. Civil servant scientists need to strike a delicate balance between the time they have committed in the ROSES proposals and the time they need to spend on bringing new work to the Center.

There is no doubt that civil servant scientists continue to spend an increased amount of time writing proposals at the expense of research, and that this has created some morale problems. Possible solutions would be for NASA Headquarters to increase the strategic FTEs made available to the Division, or to consider base funding at some level for some of the Division's activities.

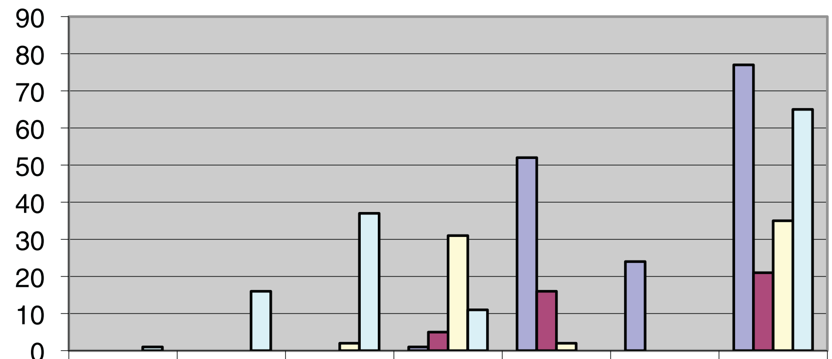
7.2 Retention of Skills and New Hires

The ESD faces significant problems relating to its aging civil servant workforce. As we look forward, we project that the number of retirements in the next 10 years will significantly deplete the core ESD civil servant staff, particularly in the leadership ranks. Our age demographics (Figure 7.1) are such that close to half of the ESD workforce can retire within the next five years, and that only about one-tenth of our workforce is between ages 30-40. The mean age of an ESD civil servant employee is now 53 years. This is the result of the low number of hires for more than a decade, and the reduction in civil servant workforce from the 1990s to the present, when we have been able to again start hiring.

For quite a few reasons, this is a serious and ongoing problem. It may take 10 to 15 years for a newly minted Ph.D. to develop the scientific credentials and management skills to lead a major scientific mission. For this reason, it is critical that the rate of influx of new scientists equals that of those retiring, and is flexible enough that transitions in capabilities to new staff can be addressed proactively, rather than when a retirement is imminent. We have made some progress during the past year, as we have been able to hire nine new civil servant scientists. This hiring has allowed us to bring on-board first-rate scientists in some focus areas. As we have done this, we have addressed some significant age demographic issues, and new, younger staff has joined some of our key groups. However, since the population overall continues to age, the problem will not go away; hence, continuing to address our many demographic issues remains an extremely high priority for the future.

As we work to hire new staff, we apply the following basic criteria:

- Quality of the candidate;
- Gaps in the expertise existing in a focus area of research;
- Relevance to existing or possible space missions, in particular in relation to acquiring and implementing the NASA missions recommended



Age	Under 25	25-35	36-45	46-55	56-65	Over 65	Total
Retirement Eligible w/in 1 year	0	0	0	1	52	24	77
Retirement Eligible w/in 5 yrs.	0	0	0	5	16	0	21
Retirement Eligible w/in 10 yrs.	0	0	2	31	2	0	35
Ineligible	1	16	37	11	0	0	65

Figure 7.1. Demographics for the Division's workforce. It is clear that close to half of the work force is eligible for retirement within the next five years, and that we need to hire more young scientists to replace the senior scientists.

by the NRC Decadal Survey and in winning Venture Class missions;
- Relevance to the research activities sponsored by NASA Headquarters and to our ability to play an important role in the science of weather and climate; and
- Relevance to the application activities sponsored by NASA Headquarters in applying scientific results for the benefit of society.

Although the role of the candidate towards the goal of achieving a diversified workforce is a consideration, we make every attempt to build the best and most diversified talent pool, rather than using demographics as a screening approach when making final selections of candidates. Thus, our preferred approaches to screening would include actions such as recruiting at particular universities, or making special calls for early-career scientists.

7.3 Some Measures of Our Performance

Determining the appropriate performance assessments for a government laboratory (such as the ESD) is not a simple matter, for it is difficult in the short term to assess the long-term impact of research. In our case, we can ask several questions:

- How good is our publication record?
- How successful have we been in winning research proposals?
- How successful have we been in advocating for new missions for NASA and specifically for GSFC?
- How well have we performed in support of projects?
- How well have we enabled the research community?
- How well have we supported the education of the general public, and of the university community in particular?
- How well have we served the activities of our professional societies?
- How well have we transitioned science research results to end users?

We provide here some quantitative data with the Appendices showing more details.

Research Activities:

- The winning rate for ROSES proposals has varied from 39 to 44 percent during the last 4 years.
- 357 refereed publications in calendar year 2010; 380 refereed publications in calendar year 2009; 431 refereed publications in calendar year 2008; and 403 refereed publications in calendar year 2007.
- Field campaigns in FY 2010:
  - 8 scientists were PIs in field campaigns.
  - 4 scientists were Co-PIs in field campaigns.
  - 18 were Co-Is in field campaigns.

Project Support:

- 34 scientists are project scientists or deputy project scientists for missions in operation or in development.

Interactions with the Academic Community:

- 7 active Joint Centers, such as JCET, GEST, ESSIC, etc.
- Summer programs for undergraduate and graduate students.
- 20 graduate students' studies were supported at the Joint Centers since 2002.
- 34 scientists were thesis advisors in academic year 2010.
- 10 courses taught in academic year 2010.

Service to Professional Societies:

- 18 scientists are fellows of professional societies.
- 27 scientists are members of committees of professional societies.

Awards:

- 7 scientists have received GSFC or NASA awards in calendar year 2010.
- 9 scientists have received national and international awards in calendar year 2010.

Part II

Our Scientific Foci and Strategic Plan

8. ESD Science/Research Areas

This chapter outlines the science activities within the research and technical groups in the Division, and identifies our plans for the coming five years. This part of the document is organized by scientific research area; links to the activities outlined in Chapter 5.1, Table 5.1.

8.1 Atmospheric Composition

Atmospheric composition research within the Division includes the atmospheric chemistry and aerosol composition of the atmosphere, which are essential radiative components of the Earth system and drive its energy balance while affecting air quality. The research in this area involves taking extensive measurements from space to assess the current composition and to validate the parameterized processes that are used in chemical and climate prediction models. Division scientists are involved in instrument and mission development campaigns that validate data from space missions using ground-based and aircraft instrumentation, ground-based networks of validation measurements such as AERONET, data analysis from these activities, data analysis model development, and developing and distributing data sets to the research community.

8.1.1 Atmospheric Chemistry

Our chemical research activities date back to the first satellite ozone missions, and now include a strong presence in the development and operation of satellite and aircraft instruments, as well as chemical and climate prediction models. The major goal of the ESD atmospheric chemistry research is to understand both the composition of the Earth's atmosphere and its changes in response to human-produced compounds, especially in regard to recovery of the ozone layer. A growing strategic goal addresses the long-term changes in the chemistry of the troposphere and the importance of long-range transport of chemical constituents, and the relationship of both to climate change and surface emissions relevant to air quality. To attain these goals we use a combination of observations and modeling activities.

The atmospheric composition group at GSFC and GISS address the following basic scientific questions:

Scientific Questions

- How do anthropogenic activities impact atmospheric pollution at regional and global scales?
- What is the impact of long-range transport of pollutants on local air quality?
- How will climate change impact local air quality?
- How will changes in atmospheric composition influence climate change?
- How will the stratospheric cooling associated with climate change impact the spatial extent and recovery of the ozone layer and the Antarctic ozone hole?
- Is stratospheric ozone recovering in a manner expected from theoretical predictions?
- How well can we predict atmospheric chemical impacts on ozone and climate?
- What are the impacts of short-lived species on climate, air quality, and public health?
- How would specific policy instruments impact climate and air quality?
- What are the climate feedbacks involving radiatively active species in the atmosphere (including ozone and aerosols)?

The atmospheric composition group's heritage in collecting and analyzing satellite data includes:

Heritage

- Major contribution to the understanding and documentation of the ozone hole.
- Major contributions to understanding stratospheric chemistry and dynamics.
- Increasing role and contributions in tropospheric chemistry, due to our leadership function in the Aura mission.
- Major role in missions such as the TOMS series, UARS, the SBUV series, and Aura.
- Production of important long-term ozone data set.
- Two- and three-dimensional modeling to understand ozone, chemical transport, and chemistry/climate coupling.
- Major role in international ozone assessments.
- Continuing responsibility in monitoring and studying the stratospheric behavior, as mandated by Congress.

ESD Atmospheric Composition activities are closely linked to NASA Headquarter's priorities and to the missions recommended in the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Atmospheric Composition and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: >2020]
  - GACM (Global Atmospheric Composition Mission) [timeframe: >2020]
  - ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons) [timeframe: 2020]

8.1.1.1 Observations of Chemical Constituents

Atmospheric chemistry research encompasses the radiative and dynamical processes associated with tropospheric-stratospheric exchange, ozone recovery and its relationship to climate change, transport of various chemical species in the troposphere and stratosphere, and heterogeneous chemistry - including aerosols. Over the last 30 years the main efforts of ESD scientists in atmospheric composition have concentrated on stratospheric ozone. The first daily observations of total column ozone were produced that give near-complete global coverage beginning in late 1978 using the Nimbus 7 TOMS instrument. A major achievement of TOMS was the first mapping of the Antarctic ozone hole (see Figure 8.1). Data from TOMS have very high long-term precision, better than one percent per decade, and hence have become important data for assessing global ozone trends. Data from the OMI instrument on Aura are now being used to continue this high-quality ozone time series. The total ozone data were initially derived using a simple algorithm, but as a by-product of algorithm research to increase the accuracy of the ozone time series, new data products such as SO_2, column aerosols, and ultraviolet-B (UV-B) levels have been developed. In addition to TOMS, a number of other instruments have been developed and flown to assess ozone profile information. These other instruments include SBUV, the Shuttle Solar Backscatter Ultraviolet (SSBUV), and the combined Shuttle Ozone Limb Scattering Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE). In addition, algorithms are being developed for the Ozone Mapping and Profiler Suite (OMPS), which will be flown on NPP and JPSS.

With the launch of EOS Aura, a significant portion of the research staff is analyzing and validating Aura data. This includes Division-led validation missions, plus research and the archiving of data products. The current research focus is on analyzing data from OMI. OMI is a Dutch-Finnish-built instrument that has been flying on NASA's EOS Aura satellite since July 2004. OMI is an advanced hyperspectral instrument that operates in the UV and blue wavelengths. OMI extends and improves the SBUV and TOMS records, and adds several atmospheric species related to air quality, including tropospheric O_3, NO_2, SO_2, HCHO, CHOCHO, and BrO. This effort will continue for at least another decade with OMPS instruments, that will fly on the NPP and JPSS. satellites, plus the Global Ozone Monitoring Experiment (GOME) series of instruments on the European MetOp satellites. These measurements will also be enhanced by the deployment of the Stratospheric

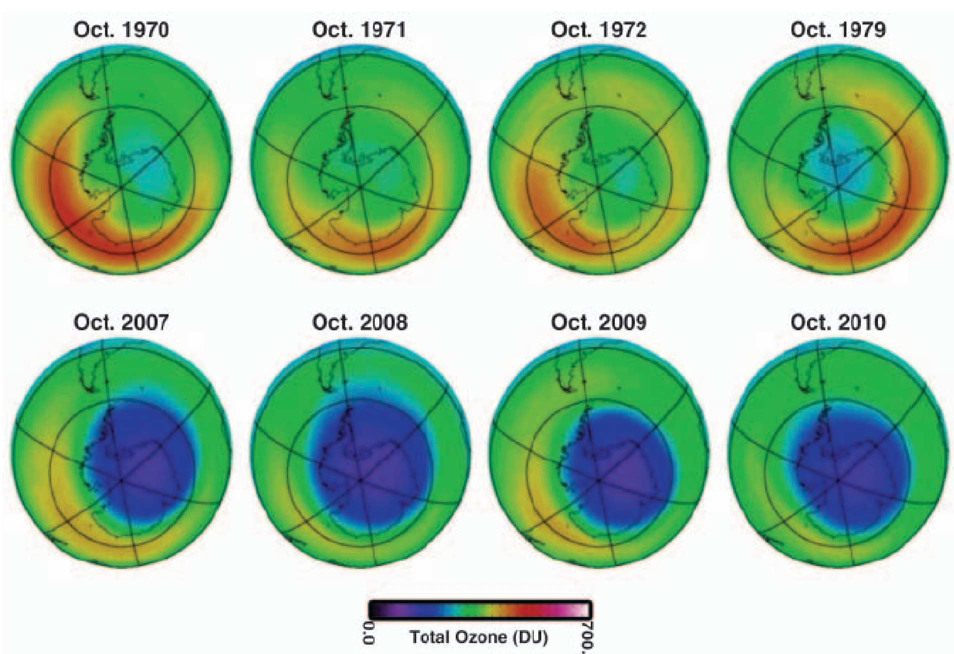


Figure 8.1. October Antarctic Column Ozone

Aerosol and Gas Experiment (SAGE) III instrument aboard the International Space Station, targeted for 2014.

These instruments also provide information about light penetration inside clouds. The launch of CloudSat into the A-Train, next to Aura has demonstrated that the cloud pressures provided by UV/Vis measurements (referred to as *optical centroid cloud pressures*) are distinct from the physical cloud top and more appropriate for use in UV/Vis trace-gas retrievals. In the future, TOMS ozone data will be reprocessed with a cloud climatology based on OMI data. Measurements of SO_2 and aerosol index from OMI have also proven very useful in tracking the path and impact of recent volcanic eruptions (See Figure 8.2). ESD scientists are also involved in satellite constituent retrievals from thermal infrared instruments, such as the Aqua Atmospheric Infrared Sounder (AIRS). For example, ESD scientists provided near-real-time retrievals of carbon monoxide (CO) from AIRS in support of multiple field campaign missions. The CO data are also used to validate long-range transport in ESD models.

SMD at NASA Headquarters has developed the "Measurement Team" concept, putting the responsibility for scientific satellite data sets as close to the users of that data set as possible. ESD staff, and in particular the ozone group, have pioneered this concept, taking responsibility for retrieval algorithms, instrument calibration, and working with data users toward the goal of creating the highest-quality data sets. This has included using satellite data from NASA and European research instruments, as well as NOAA operational instruments. ESD scientists continue to improve the quality of these data records by incorporating advances in forward and inverse modeling and calibration methods. As a by-product of this activity, several long-term data sets, some of them spanning almost 40 years. These data sets include the TOMS series of instruments that include volcanic sulfur dioxide, UV-B, and UV-absorbing aerosols produced by biomass burning and desert dust. ESD staff will continue this scientific data set production by creating a science quality ozone data set from Nimbus 7 TOMS (1978), through EOS OMI (2004), on to OMPS on NPP (2011), and on to the JPSS era (2014) as discussed in Chapter 8.6.1.

During the next three years we will combine the reflectivity data from all of the TOMS, SBUV-2, OMI, and SeaWiFS instruments to create a climate data record stretching back to 1979. This data record will be extended using GOME and the future NPP and JPSS satellite instruments. Based on the first year's work, we will be able to determine whether there has been any long-term change in cloud cover over the land and oceans in response to global warming. Preliminary results indicate that there has been a small increase in cloud cover that is consistent with the independently developed data that indicate global dimming due to increased cloud cover (i.e., less light reaching the Earth's surface). In addition, we have found local areas of decreasing cloud cover over parts of Europe and the United States, leading to increased amounts of UV exposure.

In addition, analysis of the data from the Upper Atmosphere Research Satellite (UARS) is providing a better understanding of the trends and variability of stratospheric ozone, and has helped guide government policy for the regulation of ozone-depleting substances. The Division continues to work with other data sets, including those from such occultation instruments as the Polar Ozone and Aerosol Measurement (POAM), SAGE III, the Aerosol Characterization Experiments (ACE), and the

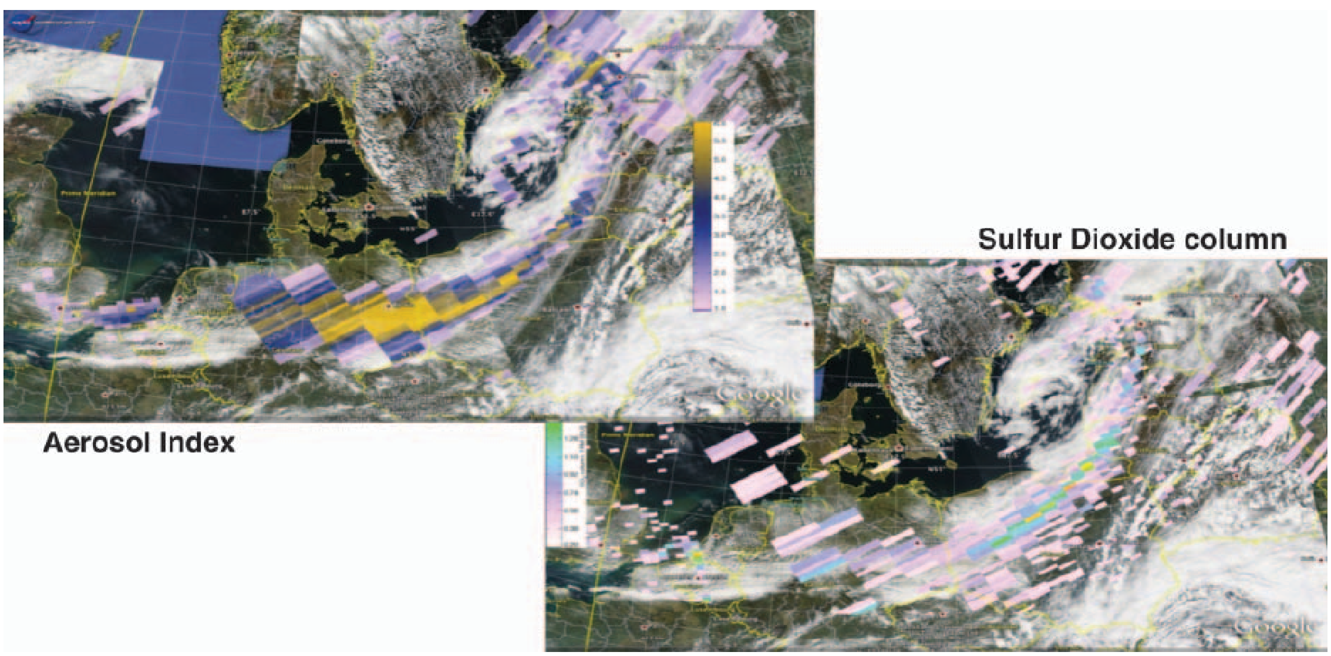


Figure 8.2. OMI Images of Aerosol Index and SO2 plumes on April 16, 2010, from the eruption of the Eyjafjallajökull volcano in Iceland.

Halogen Occultation Experiment (HALOE), as well as data from GOME and the Environment Satellite (ENVISAT).

Over the next five years, ESD ground- and aircraft-based observations will be focused on: continued support for satellite measurements, including those from Aura and Aqua; the ground-based Network for the Detection of Atmospheric Chemical Change (NDACC); and the Southern Hemisphere Additional Ozonesondes (SHADOZ) balloon network. In particular, the NDACC will be supported by the Stratospheric Ozone Lidar Trailer Experiment (STROZ-LITE), which will measure ozone aerosols, temperature, and water vapor profiles; by the Aerosol and Temperature Lidar (ATL), which will measure aerosol scattering, extinction, and depolarization, plus stratospheric and tropospheric temperature, and water vapor; and the Atmospheric Lidar for Validation, Interagency Collaboration and Education (ALVICE) system, which is the standard for Raman measurements of water vapor profiles. In the near future, a tropospheric ozone lidar capability will be added to the ATL to provide validating observations for OMI comparisons. MPLNET recently formalized an agreement with NDACC, each becoming a participating network in the other. The addition of MPLNET sites within NDACC expands their aerosol capability, particularly boundary layer observations. All data from these lidar instruments are also used in support of Aura measurements, and includes the Global Hawk Pacific Experiment (GloPac), which was the first science mission flown on the Global Hawk Unmanned Aircraft System (UAS). Work continues on the development of a ground-based CO_2 lidar to make routine, highly accurate profile measurements for monitoring and field mission support. ESD scientists are collaborating with scientists from Langley Research Center to develop downward-looking ozone lidar instruments for future Global Hawk and ER-2 aircraft missions.

During the past two years, new, accurate, ground-based, low-cost instruments (Pandora and Cleo costing less than $12,000 each) have been developed to measure trace gas amounts and aerosol properties, to validate satellite measurements (OMI, GOME, and future NPP and NPOESS instruments), to explore the details of tropospheric chemistry, and to determine air quality at multiple sites. The current three Pandora spectrometers will be expanded to a network of 20 instruments at sites throughout the world over the next two years, as well as being an important component of the DISCOVR-AQ Venture Class mission (see below). The Pandora systems are capable of measuring O_3, SO_2, HCHO, NO_2, and H_2O column amounts with good accuracy (1 percent) and very high precision (0.1 percent). The Pandora system is capable of determining ozone profiles from the ground to 50 km every 15 minutes throughout the day. This capability will be of key importance for satellite validation and air quality measurements. In addition, the Pandora spectrometers can make aerosol optical property and particle size measurements as a function of wavelength from 300 to 520 nm in 0.5-nm steps. The importance of the new aerosol measurements has been established by recent shadowband data, which show that the absorption properties of aerosols in the UV are different from those based on extrapolations of AERONET data. The absorption properties in the UV permit the determination of the type of aerosol and are required for improved model estimates of tropospheric chemistry. The Cleo spectrometer systems are an advanced version of the shadowband instruments, but are capable of measuring aerosol properties from 300 to 800 nm in 1-nm steps, and also measuring column amounts of O_3, SO_2, and H_2O. Unlike the original shadowband, the Cleo version can be field-calibrated without an expensive laboratory setup. This makes them ideal for a widely distributed network of low-maintenance instruments.

The Division has also hired an experimental scientist to spearhead the development of a capability for in-situ measurements of HCHO aboard aircraft and balloons. These measurements, based on the Laser Induced Fluorescence technique, are expected to prove useful in developing new capabilities for validation of satellite data.

ESD will continue to work with NASA Headquarters to develop systems to: (1) predict global ozone change in the stratosphere and troposphere, (2) determine the impact of climate change and intercontinental transport of pollution on local air quality, and (3) establish aerosol distributions, aerosol effects on atmospheric constituents and clouds, and the combined effects on climate. In particular, ESD scientists are collaborating with NASA Headquarters in feasibility studies of the satellite missions detailed in the NRC Decadal Survey. Development of future satellite observations depends on the lessons learned from ongoing efforts with currently flying satellite instrumentation: Aura's OMI instrument, TOMS, SBUV-2, and the European instruments GOME and Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY). Studies are currently under way to refine scientific goals and measurement requirements for the GEOCAPE mission. In addition, the Airborne Compact Atmospheric Mapper (ACAM), a UV/Vis high-resolution instrument developed under an Instrument Incubator Project (IIP) project, has flown aboard the WB-57 in the Tropical Composition, Cloud, and Climate Coupling Experiment (TC^4) and Newly Operating and Validated Instruments Comparison Experiments (NOVICE) campaigns, and was also used in this year's GloPac mission. All these activities may be hampered by the retirement of experimental scientists in UV detection and calibration; new hires are needed to continue this activity and to maintain our world leadership.

Atmospheric Chemistry and Dynamics Branch (ACDB) scientists are participating in the support, execution, and development of aircraft field missions. ESD scientists provided on-site support in chemical forecast of CO and aerosols for the Arctic Research of the Composition of the Troposphere from Aircraft and Satellite (ARCTAS), during both the spring 2008 and summer 2008 deployments. Support of ARCTAS will continue through post-mission analysis of aircraft and satellite data. GloPac was the first science mission flown on the Global

Hawk UAS. GloPac flew a mix of in-situ and remote sensing instruments for supporting Aura validation, and exploring issues related to stratospheric ozone depletion, aerosol transport, and global pollution. The ACDB contributed to GloPac with project science leadership, flight planning, and the ACAM UV-Vis instrument.

In addition to GloPac, ACDB scientists were successful on a number of proposed Venture Class missions. The first Venture Class NASA Research Announcement (NRA) was released in 2010, with funding for 2011. Successful proposals have been funded to work on the Hurricane and Severe Storm Sentinel Mission (HS3) (in collaboration with NASA Ames Research Center), Deriving Information on Surface Conditions from Column and Vertically-Resolved Observations Relevant to Air Quality (DISCOVER-AQ) (in collaboration with NASA Langley Research Center), and the Airborne Tropical Tropopause Experiment (in collaboration with NASA Ames Research Center).

8.1.1.2 Chemical Modeling

Our computer-based models of the atmosphere bring together our knowledge of atmospheric processes to better understand how the system operates as a whole. Our chemical models focus on understanding the processes that determine the chemical composition of the atmosphere. ESD chemical models are used in five areas: (1) modeling of the past, and of past events, to determine what factors influenced the observed time-series of data; (2) sensitivity studies, in which input parameters to a model are varied to understand how certain processes affect the model and the atmosphere; (3) field campaigns and satellite support, to provide a complete picture of atmospheric composition; (4) incorporation of all of the above information into projections of future changes in composition on the decade-to-century time scale that will help inform the international assessment process; and (5) support for the development of new satellite instruments and sampling strategies.

The development of our chemical modeling capability is one part of the overall ESD goal to develop comprehensive Earth system models. Several chemical modeling efforts contribute to this goal, including: (1) the GSFC Earth Observing System Chemistry Climate Model (GEOS CCM); (2) the Global Modeling Initiative (GMI); (3) the stratospheric Chemical Transport Model (CTM), in both two and three dimensions; (4) the GSFC Global Ozone Chemistry Aerosol Radiation and Transport model (GOCART, described in Chapter 8.1.2); (5) aerosol micro-physics and composition modeling (also described in Chapter 8.1.2); (6) mesoscale modeling; and (7) incorporation of interactive chemistry in the GISS climate model. These efforts are used in different applications, but have a strong common element: the use of constituent observations to evaluate and improve the representation of processes in the models to provide better potential for reliable future predictions. These efforts are closely coupled to the development of the underlying general circulation model, and are part of the development process for including improved representations of processes in the model and pushing it forward toward the goal of a comprehensive Earth system model. These efforts are carried out in synergistic collaboration with the Global Modeling and Assimilation Office (GMAO), by utilizing meteorological fields for driving CTMs, incorporating chemical processes in their climate model, and providing chemical mechanisms and approximations to facilitate chemical forecasts during aircraft campaigns, and assimilation of gas-phase tracers.

A CTM requires meteorological fields for the transport of chemical species. One source is the Atmospheric General Circulation Model (AGCM) that has been developed within the Division as a component of the GSFC Earth Observing System (GEOS)-5 model and data assimilation system. The present AGCM relies on ozone climatology, with no feedback between chemistry and the other components. In a the chemistry-climate model described below, constituents are transported online, chemical changes to ozone and other constituents are calculated, and computed fields of ozone and other radiatively active constituents used as input to the radiation module. The GMAO has developed a new, computationally efficient model (GEOS-5 AGCM) with updated physics. This model also serves as the core of the new atmospheric data assimilation system and the coupled climate prediction system. Meteorological fields from this model are also used for transport by GMI, CTM, and GOCART model. Hence, one of the foci for improvements to the GEOS-5 model is to provide better meteorological fields for GMI and GOCART in addition to the assimilation, weather, and climate prediction applications. Over the next five years, the chemical modeling group and the assimilation group will jointly develop chemical forecasting models, as discussed in Chapter 8.4.3. More details on the chemical models are given below.

Chemical Transport Model and the Global Modeling Initiative

The Global Modeling Initiative (GMI) is a broad community effort funded by NASA Headquarters, and managed by ESD. The goal of GMI is to develop and maintain a state-of-the-art modular 3D CTM that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. The GMI CTM includes both tropospheric and stratospheric chemistry, and is being used to realize fully the benefits of the trace gas measurements in the lower stratosphere and troposphere that are being made by instruments on Aura. Such applications are a prerequisite to interpretation of simulations using the fully coupled version of GEOS-5 (see below). In addition, the CTM also includes aerosol modules such as GOCART as well as microphysical modules. The GMI chemistry has been incorporated into the GEOS-5 framework to allow for future coupled chemistry-climate simulations encompassing both the troposphere and the stratosphere. Current efforts are targeting the full incorporation of the GMI model into the GEOS-5 framework, allowing for a CTM capability within the same computational framework.

A particular focus of GMI is to reduce the uncertainty in assessments by making it possible to determine the sensitivity of results to various model components. GMI will be mainly used for producing hindcasts, forecasts, and sensitivity studies.

Chemistry-Climate Model (CCM)

The chemistry-climate model is now in its sixth year of development. This effort is a collaboration between the ACDB and the GMAO. It combines the CTMs developed in ACDB with the GEOS General Circulation Models (GCMs) developed in the GMAO. The first version of this effort coupled the 3D stratospheric CTM developed over the past two decades in the ACDB with the GEOS-4 atmospheric GCM. The goals of this effort were to better understand how the recovery of the ozone layer would take place as the underlying climate changed, and how the ozone depletion and recovery might affect the climate. The model has been used to carry out "world-avoided" simulations (see Figure 8.3), which show the catastrophic impact of increasing CFCs, if the Montreal Protocol had not been put into place. This version of the model was used as part of the 2006 World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) Ozone Assessment, and has been part of an international intercomparison of chemistry-climate models. An updated version of the model now couples the stratospheric chemistry to the GEOS-5 atmospheric GCM. This version was used to support for the 2010 WMO/UNEP Ozone Assessment. A third version that uses the combined stratosphere-troposphere chemistry (Combo) developed by GMI is now also available. This version includes the seamless prediction of ozone in both the troposphere and stratosphere for better evaluation of its impact on climate change. The future for the chemistry-climate modeling effort includes both improvement in the underlying model through extensive data comparisons and extension of the coupling in the model to include the aerosol-chemistry processes, land surface processes, and the ocean-atmosphere GCM.

Mesoscale Chemical Modeling

Global-scale models are currently too computationally costly to reasonably resolve urban-scale (<10 km) chemical composition. For the urban-scale chemical composition, mesoscale models have been developed that include large-scale boundary inputs from global-scale models. The mesoscale modeling effort is currently being developed to support satellite and field missions, sensitivity studies, and satellite mission development. We are currently using and refining the Weather Research and Forecasting (WRF) regional model to include aerosols and chemistry in a way that is (1) flexible in terms of spatial resolution (from sub-100 km to a few km) and geographic location and is ready to run in forecast, analysis, and testing modes; and (2) can be nested within the global model to study the regional-global interactions. This model is also a component of the definition studies for future missions.

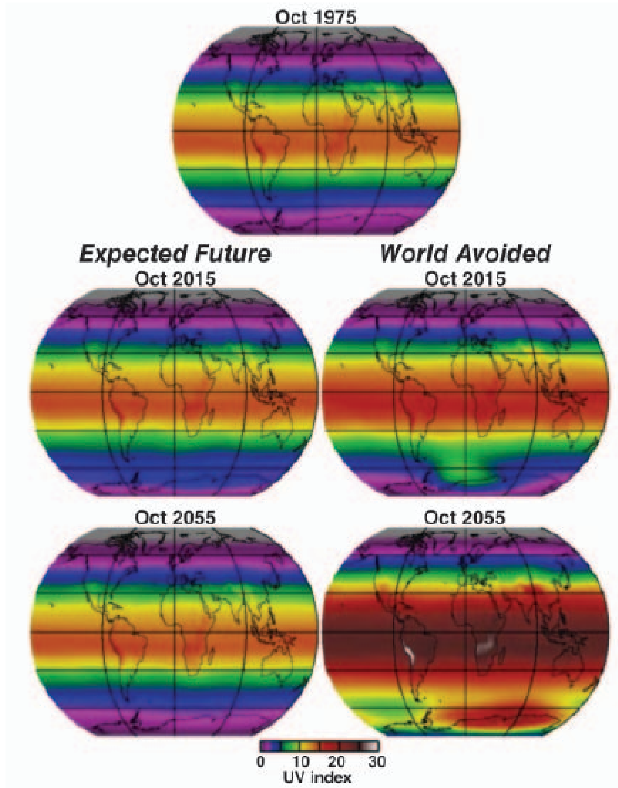


Figure 8.3. Expected UV index calculated assuming the future emissions of ozone-depleting substances (ODS) regulated by the Montreal Protocol (left), and what it would have been if the ODSs would have grown unchecked at rates prior to the Montreal protocol (right). The UV index would have tripled over the whole globe by 2065.

GISS model for Physical Understanding of Composition-Climate Interactions and Impacts (G-PUCCINI)

The G-PUCCINI component of GISS ModelE is an online calculation of whole-atmosphere chemistry based on a family approach. It includes approximately 150 reactions and 35 advected tracers. It has been used to assess the impact of specific emissions on climatically important atmospheric constituents (including methane and ozone), and to assess the climate feedbacks involving short-lived components. It is a key component in the long-term model simulations for CMIP5 in support of the IPCC's Fifth Assessment Report.

Future Chemical Research

In the near term, we are focusing on the questions of how ozone will recover in a changing climate and how that recovery will affect the climate. With the version of the CCM that includes the combined stratospheric-tropospheric chemistry, we will begin to ask questions about how stratospheric ozone recovery affects tropospheric chemistry and, possibly, air pollution. Simulations with our first version of the CCM have shown how stratospheric ozone and circulation are expected to respond to climate change driven by greenhouse gases (GHG). Simulations that cover the period from 1950 to 2100 have shown that, as Ozone Depleting Substances (ODS) are removed from the stratosphere, ozone does not recover to the same distribution as existed before ODS were introduced. This is because of stratospheric cooling due to GHG and a possible change in the circulation of the stratosphere. We will do several simulations with the combined stratospheric-tropospheric chemistry to evaluate separately the response of tropospheric chemistry to changes in both ODS and GHG. Longer-term plans for this version of the model will include biogeochemical processes at the surface that can respond to changes in climate, thus providing variable inputs of chemicals to the atmospheric system. This advanced version of the model will assess the interaction of GHG and ODS with natural biological processes.

One of the results from our present studies is a better understanding of the role of sea-surface temperatures (SSTs) in the circulation and composition of the stratosphere. The atmospheric GCM uses SSTs specified from either observations or from simulations by coupled ocean-atmosphere models. The sensitivity of many of our results to SST assumptions highlights the importance of moving the CCM toward the use of a coupled ocean-atmosphere GCM. The development of such a model in GMAO provides us with an opportunity to further extend the coupled CCM in this direction.

Another important direction for extending the coupling of processes is in the area of aerosol-chemistry interactions. The GOCART model (described in Chapter 8.1.2) has been implemented within the GEOS-5 framework and independently within GMI. The GMI implementation focuses on the issues of chemistry-aerosol interactions. These two implementations have been brought together within the GEOS-5 CCM framework to full couple aerosols to both the chemistry and the circulation of the atmosphere. Part of this task involves making the important connections with natural sources of atmospheric chemicals, particularly sulfur compounds and organic compounds. These developments are enabled by the fact that we now have global satellite data from Aura and other satellites for some of the key compounds. Without these data, we could develop the models to include processes, but would have no way to test their validity, thus limiting the advancement of knowledge.

The GMI/GOCART CTM capability is an important part of the testing of the chemical coupling throughout the atmospheric system, especially the relationship of the composition to sources and to the variations with changing climate. The CTM framework, both for GMI and GOCART, make for straightforward interpretation of sensitivity studies. The CCM framework couples many interactions to get a representation of important feedback process, but this coupling can make sensitivity studies hard to interpret.

The mesoscale chemical model will continue to be used in the next few years for studies showing how high-resolution satellite measurements of tropospheric pollution will lead to a better understanding of pollutant transport from local sources to regional and global scales. It will also be used for satellite mission support and data analysis for aircraft and other specific field experiments.

Future Hiring Needs

During the past five years, the Atmospheric Chemistry and Dynamics Branch has hired five new scientists. At the same time, three scientists have retired, and an additional seven will be eligible for retirement in the next five years. If the branch is to maintain its national leadership in atmospheric observations and modeling, it is crucial that the hiring of new civil servants continue at the same or higher rate than in the past five years. In particular, the branch has strong needs of hires in the following areas: (1) remote sensing scientists, with expertise in both the UV and IR; (2) an instrument scientist to help develop future satellite sensors in the UV, with knowledge of radiative transfer techniques; (3) a modeler with expertise in tropospheric processes, in particular those that impact the Earth's climate; (4) a modeler with expertise in stratospheric processes and their interaction with climate change; and (5) a modeler with expertise in inverse modeling and/or chemical data assimilation.

8.1.2 Atmospheric Aerosols

Atmospheric aerosols are an essential component of the Earth's climate system, perturbing the Earth's energy balance and influencing the hydrological cycle, precipitation, and weather. Aerosols both reflect and absorb solar radiation, which may counteract global warming from greenhouse gases in some places, but can also redistribute energy within the atmospheric column, and in some cases amplify the warming regionally. Aerosols are key to understanding climate change, as they represent the largest single uncertainty term in the global radiative forcing budget, according to the IPCC. Aerosols-related activities at GSFC are well recognized nationally and internationally. They are central to at least two of the six NASA Interdisciplinary Science Focus Areas—Atmospheric Composition and Climate Variability and Change—and they are directly related to the following missions recommended in the NRC Decadal Survey: GEOCAPE and ACE, as well as the NASA Earth Observing System's Multi-angle Imaging SpectroRadiometer (MISR), the Moderate Resolution Imaging Spectroradiometer (MODIS), and OMI instruments, and the upcoming Glory mission. The aerosol-related activities address the following:

Scientific Questions

- How do aerosols affect regional weather and climate?
- How do aerosols affect the Earth's heat balance?
- How do aerosols affect cloud and precipitation?
- How do aerosols affect ecosystems?
- How do aerosols affect health?

The ESD has a strong record of activities in aerosols:

Heritage

- Aerosol research at GSFC dates back to the late 1970s, beginning with NOAA's Advanced Very High Resolution Radiometer (AVHRR) and the Landsat instruments.
- GSFC/GISS has hosted the NASA-Global Energy and Water Cycle Experiment (GEWEX) Global Aerosol Climatology Project (GACP) since 1998.
- The GSFC Center of Excellence in Aerosol Research (AeroCenter) was established in 2000 and has hosted hundreds of visitors, and seminars that have been broadcasted widely to other NASA centers and universities via the Internet.
- The AERONET and MPLNET were established in support of the EOS program, providing ground-based, global networks of remotely sensed column aerosol measurements.
- Radiometers, lidars, and comprehensive observational systems have been designed here to measure aerosols, water vapor, and surface reflectance. Surface-sensing Measurements for Atmospheric Radiative Transfer (SMART) and Chemical, Optical, and Microphysical Measurements of In-situ Troposphere (COMMIT) are two such examples.
- The Glory mission was conceived at GSFC and is managed here.
- Major use of data is made from TOMS, MISR, MODIS on Aqua and Terra, OMI on Aura, ICESat, CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO).
- Modeling and data assimilation efforts have been conducted to study the transport of aerosols and their effect on weather and climate.
- GSFC has developed and maintains major aerosol-sensing aircraft instruments, such as the Cloud Absorption Radiometer (CAR) and the Cloud Physics Lidar (CPL).
- GSFC has played a key leadership role in major field campaigns.
- Data sets produced by MODIS for aerosol optical thickness and cloud properties have been created and made available to the scientific community. GSFC partners with JPL in developing and refining the MISR aerosol products.

Relation to NASA Priorities and the NRC Decadal Survey

The activities in the aerosol area have clearly been supportive of the NASA Headquarters' focus area, and are directly related to some of the missions recommended by the NRC Decadal Survey, in the following ways:

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Atmospheric Composition and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2018–2021]
  - ACE (Aerosol and cloud profiles for climate and water cycle) [timeframe: 2018–2021]

The goals of aerosol research at GSFC are to improve our prediction of the impact of aerosols on climate and to enhance our understanding of the chemical, physical, radiative, and meteorological processes relating to aerosols. Because aerosols, clouds, and climate are inherently linked within the hydrological cycle, much aerosol research in the future will coincide with research of hydrospheric processes described in Chapter 8.2.4. Although there have been several new civil servant hires in this focus area, we are still missing some key expertise to address the interaction of aerosols, rainfall, clouds, and large-scale circulation.

Cloud, aerosol, and radiation area research priorities have focused on the retrieval of optical and radiative properties of clouds and aerosols. These data sets are listed in Chapter 8.6.1. Data from the AVHRR, Terra (MISR and MODIS), Aqua (MODIS), Aura (OMI), CALIPSO (CALIOP), TOMS, and SeaWiFS were used in this research. Increasingly, aerosol retrievals are attempting to address more difficult parameters or situations such as aerosol microphysical properties or aerosol amount above clouds. More frequently retrievals using multiple sensors are employed. The "A-Train", a series of satellites—Aqua, CALIPSO, CloudSat, Polarization, and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) and Aura—will be making near-simultaneous observations because they are clustered together along the same orbit path. This enables us to develop joint retrieval algorithms using the combined strengths of individual sensors and to focus on cloud-aerosol-climate interactions. One key to current remote sensing of aerosol processes is the measurement of aerosol vertical distribution by CALIPSO's lidar. Some additional information about particle type can come from polarization measurements by the Polarization and Directionality of the Earth's Reflectance (POLDER) on PARASOL. Over the next five years, the aerosol group will be analyzing the aerosol data from the A-Train and Terra, and combining these observations with detailed suborbital measurements of aerosol type to provide a more complete global picture. Much more detailed and precise aerosol retrievals will be obtained from polarization measurements from the Glory Aerosol Polarimetry Sensor (APS), a passive instrument with the potential to infer aerosol chemical composition, as well as retrieve detailed aerosol and cloud particle size distribution and shape information in cloud-free areas and above clouds. Glory launch is expected February 2011. Combined analyses of APS and CALIPSO data are expected to yield the first vertically resolved retrievals of aerosol microphysical and compositional properties. Measurements of some key parameters will continue through NPP and JPSS, and we look forward to the implementation of a specific measurement team for clouds and aerosols in the NPP era. These new tasks will also require additional senior staff.

A strong modeling component will continue to be part of the satellite program. The GOCART aerosol transport model has proven to be very successful in providing a framework for assessing our understanding of sources and sinks and transport of various aerosol and chemical species. With the coupling of GOCART with the GEOS-5 AGCM and the beginning of a robust assimilation of satellite aerosol information into the models, we are beginning to expand the studies of chemical transport modeling and assimilation, including the feedbacks that impact not only climate but also weather prediction.

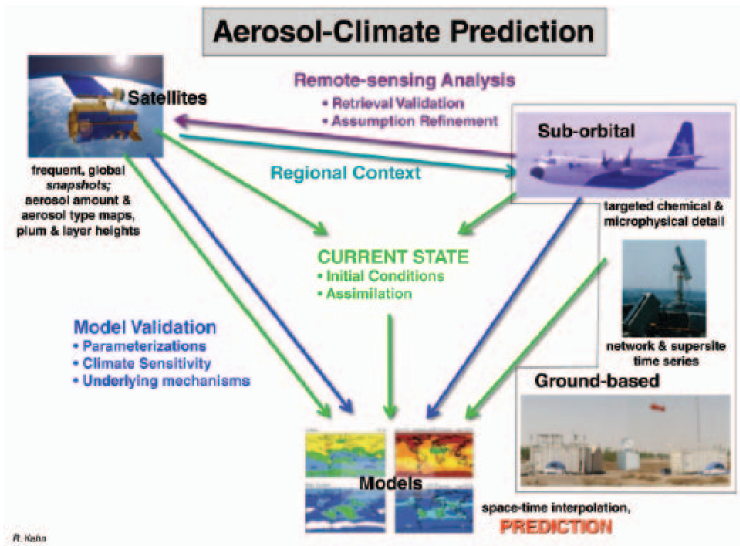


Figure 8.4. Aerosol-Climate Prediction.

Within the next five years, the aerosol research focus will be:

Description of the Global Aerosol Distribution and Optical Properties

We are moving toward a synthesis of sensors and techniques to improve remote sensing of the aerosol properties. Using new satellite data, ground networks (such as AERONET and MPLNET), and new techniques that include 3D radiative transfer, we intend to create a long-term climate data record and a new aerosol assimilation system. These satellite data will come from MODIS, MISR, OMI, CALIPSO, PARASOL, and later, Glory APS. The APS in particular will provide aerosol microphysical and compositional parameters in the format directly compatible with model outputs and assimilation system inputs. These data will be combined with comprehensive ground-based remote sensing, along with ground-based and aircraft and in-situ measurements, and used to constrain aerosol models, through assimilation or adjustment of model parameterizations and boundary conditions, to generate cohesive data sets, and also to interpolate into cloudy regions and to fill in places and times where satellite aerosol retrievals are lacking. We will use the combination of observations and model simulations to determine sources and sinks of aerosol, and to study processes not well understood. This global distribution of aerosol can then be used to assess the effects on climate, human health, and natural hazards.

Determining the Effect of Aerosols on the Direct Forcing of Climate

Our current assessment of aerosol radiative forcing is hindered by our incomplete knowledge of aerosol optical properties—especially absorption—and our current inability to determine the aerosol distribution near, under, and above clouds. Major thrusts for the future will therefore address the determination of aerosol absorption from suborbital and other remote-sensing measurements, and improved ability to quantify aerosol loading above clouds using sensors such as OMI, MODIS, MISR, CALIPSO, and APS for detailed aerosol characterization. These measurements, together with improved data assimilation techniques, will significantly improve our understanding of the direct radiative forcing of the aerosol in the presence of clouds and over varying surface properties. APS retrievals of aerosol microphysics and composition will be used to improve estimates of the anthropogenic component of the aerosol direct radiative forcing.

Effect of Aerosols on Clouds, Precipitation, and Indirect Forcing

Direct radiative forcing by aerosol constitutes only part of the aerosol effect on climate. Aerosols also have an effect on clouds and precipitation. These effects depend on aerosol size- and on composition-dependent hygroscopicity, on the dynamic and thermodynamic properties of the cloud field, and on the perturbations to atmospheric stability caused by vertical distributions of absorbing aerosol. Simultaneous precise measurements of aerosol properties and the cloud field from satellites, coupled with cloud resolving models such as the Goddard Cumulus Ensemble (GCE), should provide the basic relationships between aerosols, microphysical properties, reflectivity of clouds, and rate of precipitation. In order to establish a definitive cause-and-effect relationship between the aerosol and the cloud-precipitation field, the models need to assess the likelihood of alternative causes for the apparent correlation between aerosol and clouds. To help address these issues, we need to employ global models that represent atmospheric circulation patterns, and plan to improve the model physics by incorporating aerosol microphysics within the convective parameterization scheme of GEOS. Then, carefully controlled model experiments and comparisons with observations will be needed to sort out the complex relationships.

Assessing Past Climate Forcing by Aerosols

In studying today's aerosol-laden atmosphere, we can use reanalyzed historical data sets to describe past aerosol distribution and forcing using the 25-year record of AVHRR and TOMS (see Chapter 8.6.1). Because these sensors are now flying simultaneously with more modern suite of instruments, the data sets can be compared with MODIS, MISR, and AERONET to improve the measurements. In essence, we can "calibrate" the old data with the new, and then assess the past with a "calibrated" time series. Sensor calibration drift affects retrieval results and is a major challenge to overcome. Published studies and instrument calibration teams are working to meet this challenge and produce a robust aerosol time series. The inherently precise calibration of polarization measurements with APS and similar polarimeters will help establish benchmark reference points in the long-term aerosol record and fine-tune aerosol retrievals with other instruments such as MODIS. This time series will itself become the test bed for predictive models that will use the lengthy observational record for evaluating the models' ability to simulate interannual variability and interdecadal trends. The Global Aerosol Climatology Project will provide a satellite-based data set spanning these multiple sensors (see Chapter 8.6.1). The tuned models then travel even further back in time to give us a glance at pre-satellite and pre-industrial aerosol distribution, with limitations. At present, a coupled aerosol-GEOS-5 climate model (aerosol direct effect only) is being tested. In a few years, a fully interactive aerosol-GEOS-5, including direct and indirect effects, will be available. This model can be used to simulate past climate, and provides future climate projections under various greenhouse gases forcing scenarios, with realistic aerosol forcing and dynamical responses. The climate data record and model assimilation will continue beyond the Terra and A-Train era, as NPP and JPSS—and eventually ACE—will provide a continuing data stream.

The interactive aerosol component in GISS ModelE is similarly being used in historical simulations for the 20th Century, and selectively for time-slices in the further past. Aerosol changes are implicated in the cooling of the last ice age, and may have a role in "greenhouse" climates of earlier periods.

Assessing the Effects of Aerosols on Air Quality and Human Health

Satellite observations are currently expanding the capability of air quality forecasting in the U.S. As remote sensing techniques improve to better characterize the 3D spatial distribution and properties of the aerosol, we will continue to work with our partners in other federal agencies to improve air quality forecasting techniques. Satellite data coupled with global models will also bring a global perspective and quantification of the long-range transport of air pollutants.

8.2 Hydrospheric Processes

Hydrospheric processes encompass all aspects of the Earth's global water cycle, including the cryosphere, land surface hydrology, physical oceanography, coastal zone processes, atmospheric precipitation and moisture, plus the techniques for observing, modeling, and prediction of these processes. There is significant overlap between the hydrospheric and atmospheric research activities within ESD.

8.2.1 Oceanography

The relatively large mass and heat capacity of the world's oceans make them essential to any discussion of climate change, both in terms of thermal- and carbon-related issues. The ocean is habitually a hostile environment for acquiring in-situ measurements; thus, detailed knowledge of the ocean's role in climate change and carbon processes is limited. Satellite measurements are the only viable option for obtaining global information about the ocean on the temporal scales necessary to resolve key ocean processes. GSFC's leadership in satellite-based oceanography is evident from its initiatives and very strong participation in project work, data processing, and NASA science teams.

The GSFC ocean community addresses the following basic inquiries:

Scientific Questions

- How does the ocean circulation and biology contribute and react to changes in the global climate system?
- What is the character and variability of the global ocean biology that is detectable through changes in ocean color?
- What are the feedbacks between surface layer dynamics, biology, and optical properties?
- What is the role of ocean sequestration of heat and CO_2 in the transient climate response to greenhouse gas emissions and the perturbation lifetime of CO_2 in the atmosphere?
- Do dynamic ocean responses affect regional climate changes, particularly in the North Atlantic? Are these changes predictable on a decadal timescale?

Heritage

- Leadership in the development and build of a new ocean color measuring instrument, Ocean Radiometer for Carbon Assessment (ORCA)

designed to meet the Pre- Aerosol-Cloud-Ecosystem mission (PACE) and ACE mission requirements.
- Leadership in the science team for MODIS (oceans), NPP/Visible Infrared Imager Radiometer Suite (VIIRS), and SeaWiFS.
- Responsibility for MODIS (color and sea-surface temperature) and SeaWiFS (color) data processing and data distribution.
- Responsibility for the Global High Resolution Sea Surface Temperature (GHRSST) products.
- Responsibility for calibration and validation for satellite-based ocean color data.
- Responsibility for collection of high-quality, in-situ ocean data sets, development of measurement protocols, and design of new field instrumentation.
- Responsibility for providing user-friendly data processing software for ocean color and SST processing to the research community (SeaDAS).
- Integrating ocean models into fully coupled Earth System Models (ESMs).

The Division will manage the post-launch operational phases, data processing, and ground system for the Aquarius sea surface salinity mission. Aquarius is a joint project with JPL and Argentina, scheduled for launch in fall 2011.

The Division will continue to support the NPP/VIIRS and JPSS missions and teams.

The activities of the Division have direct and strong relevance to NASA Headquarters' priorities and to several of the missions recommended in the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Directly related to many of the six NASA Interdisciplinary Science Focus Areas. In particular, to Carbon Cycle and Ecosystems, Water and Energy Cycle, and Climate Variability and Change.
- Directly related to NASA's upcoming Aquarius mission
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - ICESat II (Ice, Cloud, and Land Elevation Satellite–II) [timeframe: 2012–2014]
  - SWOT (Surface Water Ocean Topography) [timeframe: 2013–2016]
  - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2018–2021]
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2018–2020]
- Directly related to the PACE ocean biology/ biogeochemistry climate data record continuity mission.

8.2.1.1 Physical Oceanography

The opaqueness of water to electromagnetic radiation creates a condition over much of the open ocean of a relatively thin, warmer upper layer shielding a much thicker, colder, and more saline layer below that is generally insulated from interactions with the atmosphere. As a result of these characteristics, critical scientific questions concerning the oceans' effects on climate involve understanding how large quantities of heat and water are transported in the thin, but high heat capacity, atmospherically driven upper layer, which represents only 3 percent of the total ocean volume, yet transports approximately the same amount of heat from equator to pole as the atmosphere. Short-term climate variability can result from variability in this near-surface layer. At the same time, the thermal inertia of the slow-moving lower layer can affect climate change on long temporal scales of up to centuries. Other questions address how changes in the stratification between the upper and lower oceanic layers affects the heat and mass transport in the slower moving but much more massive lower layer. These oceanic layers are linked through the oceanic Hadley circulation, often referred to as the meridional overturning circulation in the ocean.

The topography of the ocean's surface is largely due to the thermal expansion of water due to its temperature. For this reason, measurement of ocean surface topography is used to understand changes in the total ocean heat content and, through geostrophic assumptions, to provide an estimate of the currents that transport heat and mass in the upper ocean layers. The Division's physical oceanography research has its roots in ocean surface topography and wind measurements that led to the Ocean Topography Experiment (TOPEX)/Poseidon and QuickScat missions, and the realization that measurements of sea surface topography, temperature, and winds were all required to describe the ocean surface variability associated with climate phenomena.

The new challenge of utilizing sea-surface salinity data adds a critical state parameter for satellite-based ocean research. GSFC leadership of the Aquarius sea-surface salinity Earth System Science Pathfinder (ESSP)-3 mission includes the project co-PI, delivery of the mission-critical radiometer, algorithm development, developing the ground data system, and post-launch project operations. Aquarius data, along with fresh water fluxes and high-latitude sea-surface height estimates from ICESat II will improve understanding of the density-driven ocean circulations, particularly the longer time scale thermohaline circulations, and the vertical mixing processes that are critical to understanding exchanges of properties between the ocean and atmosphere and between the surface and interior ocean. These broad commitments to monitor changes in the ocean surface in response to climate variability and the effects on the longer time scale ocean circulations are part of the Division's five-year research goals. In addition, Division staff are active in research linked to the uninterrupted sea-surface height time series series that began in 1992 with

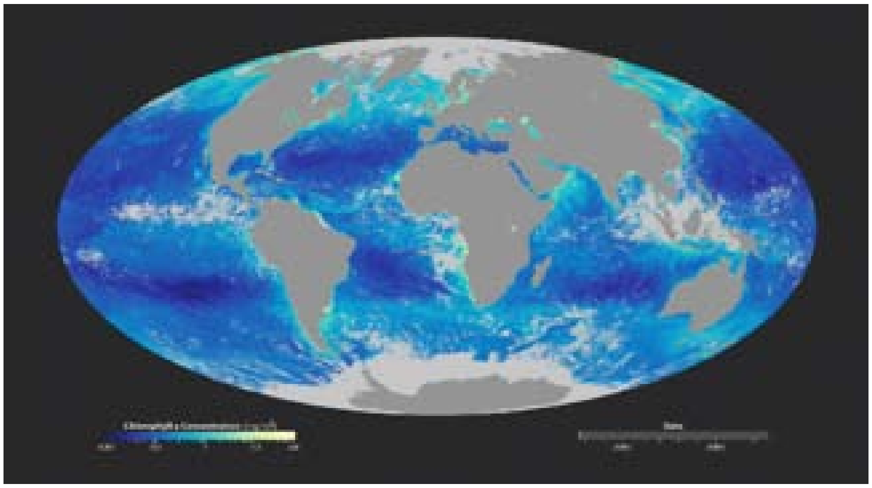


Figure 8.5. The Carbon Cycle: Phytoplankton [Sea-viewing Wide Field-of-View Sensor Orbview-2 (1997–2007)]

data from high-accuracy radar altimeters. The planned Surface Water/Ocean Topography mission will insure that this time series continues into the future, and provides an observational basis for investigating and modeling decadal- and climate-scale ocean variability, such as the Atlantic Meridional Overturning Circulation.

Ocean modeling and data assimilation

Since the ocean is one of the key components providing "memory" of the climate system, ocean modeling is incorporated into both GISS and GMAO coupled models. Both groups rely on models developed externally, with GISS using HYCOM, developed by Reiner Bleck, and the GMAO using MOM4, developed at NOAA's Geophysical Fluid Dynamics Laboratory. GISS also includes its own ocean model as a climate model option. Of course, the configuration and tuning of each model is specific to the climate model. GISS and GMAO both integrate the NASA Ocean Biogeochemistry Model (NOBM), developed at GSFC, into their system. In addition to modeling, GMAO undertakes assimilation of satellite altimeter and ocean color data, and are preparing for the assimilation of Aquarius data.

Clearly, physical oceanography expertise does not reside within a single entity in the Earth Sciences Division. The processing of satellite salinity and temperature data sets takes advantage of the decades-long learned skills of the ocean color processing group. Some of the world's foremost research in ocean tides takes place within GSFC's Solar System Exploration Division, outside of the ESD. Thus, maintaining critical skills in physical oceanography requires cooperation across divisions. The civil service expertise in ocean assimilation resides solely with the head of GMAO, and clearly requires civil service augmentation. Also, with the pending Aquarius launch pending, additional expertise in the retrieval and calibration of ocean-related microwave measurements will be crucial to the processing of new L-band measurements to insure climate-quality records from this mission.

8.2.1.2 Biological Oceanography

NASA's biological oceanography research encompasses ocean color and its relationship to oceanic primary productivity and the carbon cycle. The research and development activities extend from space missions and mission data delivery, to ocean biology laboratories that investigate phytoplankton growth and optical properties, to in-situ and remote measurement research, and a sophisticated coupled physical-biological-chemical model of the global ocean. These activities seek to clarify and, through modeling and assimilation, to predict the role of the single largest reservoir of carbon on the planet by far, the ocean, and how changes in ocean biology affect and are affected by climate change. Scientific studies, using an extensive array of ocean optics, biology, and chemistry laboratories, focus on the measurement of key properties of the surface ocean needed for expanding the remote sensing product suite, particularly those relevant to understanding marine ecosystems (e.g., phytoplankton functional group distributions) and carbon pools (e.g., particulate and dissolved organic carbon), rates (e.g., primary production), and fluxes (ocean-atmosphere CO_2 exchange).

The Division has provided quantitative global ocean bio-optical data products from the SeaWiFS Project to the Earth science community over the past 13 years. We currently support MODIS/Aqua ocean color processing and the ocean color activities associated with the JPSS program. Additionally, we provide community ocean color data product validation, sensor calibration, data merger algorithm evaluation, and satellite data processing. We continue our ongoing climate data record effort to develop and maintain a consistent multi-decadal time series of ocean color data, extending across a multitude of sensors, from the early Coastal Zone Color Scanner (CZCS) data (ca. 1978-1986), through the Ocean Color and Thermal Scanner (OCTS) (a Japanese sensor, 1996-1997), SeaWiFS (1997-present), to the current data stream from MODIS (2000-present). This consistent time series is a critical aspect of assessing climate change/primary productivity issues, and relates closely to our coupled physical-biological modeling and ocean color data assimilation, which addresses the large-scale variations in ocean color data observed from satellitesm. Since ocean color satellites observe only the near surface of the ocean, assimilation systems are essential to tie the surface observations to variations beneath the surface. This is an essential step in a comprehensive Earth system assimilation system that provides a consistent synthesis of observations across all components of this complex environment.

Our comprehensive infrastructure for analyzing field data, coupled with extensive experience in field data collection, are providing some of the highest-quality optical and biogeochemical data for inclusion in the NASA ocean bio-optical database, which is also maintained by GSFC. With the approved PACE mission and the proposed NRC Decadal Survey ACE and GEOCAPE missions, we are aggressive leaders in the definition and development of the next generation of ocean color research satellites. This includes the Ocean Radiometer for Carbon Assessment (ORCA) which is being developed under the NASA Instrument Incubator Program. Our five-year goals include continuing our ocean leadership roles for the MODIS and NPP science teams and the ACE and GeoCAPE mission working groups, successfully proposing ORCA for the PACE and ACE ocean radiometers, and expanding our field capabilities to be a core element of the PACE, ACE, and GeoCAPE field programs. We will also continue a vigorous modeling program to aid in proposing accuracy requirements and observational strategies for new ocean color missions. In addition, we will use our successful ocean biology processing system to provide an efficient mechanism for mission data processing for the upcoming Aquarius ocean salinity mission. The current GSFC leadership in ocean color will likely retire within the next two or three years. In light of this, and to achieve the objectives described above, we will need at least five new hires for the Ocean Ecology Branch to fill mission support leadership roles and to maintain a presence in ocean ecology and carbon cycle research.

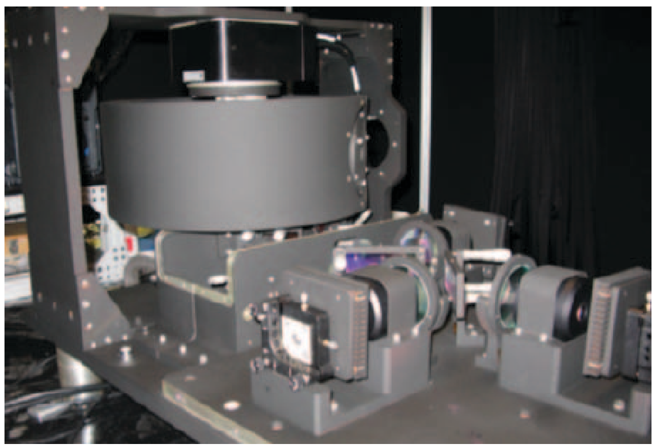


Figure 8.6. The ORCA prototype during alignment in the ORCA calibration laboratory at GSFC. ORCA is essentially a hyperspectral SeaWiFS with three SWIR bands (in the foreground of the picture). It is being developed under the NASA IIP program, and is designed to meet all the ocean color measurement and performance requirements of the PACE and ACE missions).

8.2.2 Polar Climate Change

Earth's ice cover exerts an enormous influence on global climate through the regulation of energy and moisture exchanges between the ocean, atmosphere, and land, and through the potential melting of the great ice sheets to dramatically raise sea level. The importance of Earth's cryosphere is underscored by the fact that it is one of the most sensitive aspects of the planet's climate system. This is in large part because of the positive albedo feedback associated with the melting or removal of ice. The rapid decay of Arctic ice, significantly underestimated by climate models, along with the potential instability of the Greenland and West Antarctic ice sheets and the importance and sensitivity of ice to changes in the climate system, all combine to make the understanding of ice crucial for understanding the future of the Earth system.

GSFC's cryospheric research group has been the leader in providing the space-based view of Earth's cryosphere, looking at it in ways that no other organization can. GSFC has produced algorithms, data sets, and information that have greatly enabled the broader scientific community to engage in cryospheric research. This in turn, is reshaping scientific and societal understanding of the cryosphere. ICESat was conceived and implemented at GSFC, and is producing major advances in the observation and understanding of the polar regions. Algorithm development and data analysis are occurring in parallel with major efforts in developing the technology associated with laser altimetry.

The GSFC group addresses the following basic science questions:

Scientific Questions

- How will changing ice cover contribute to future sea level, and over what time scales?
- Will there be catastrophic collapse of the major ice sheets?
- What will be the influence of changes in land ice on the climate system, the water cycle, and the biosphere?
- How will changes in sea ice affect climate and climate processes?

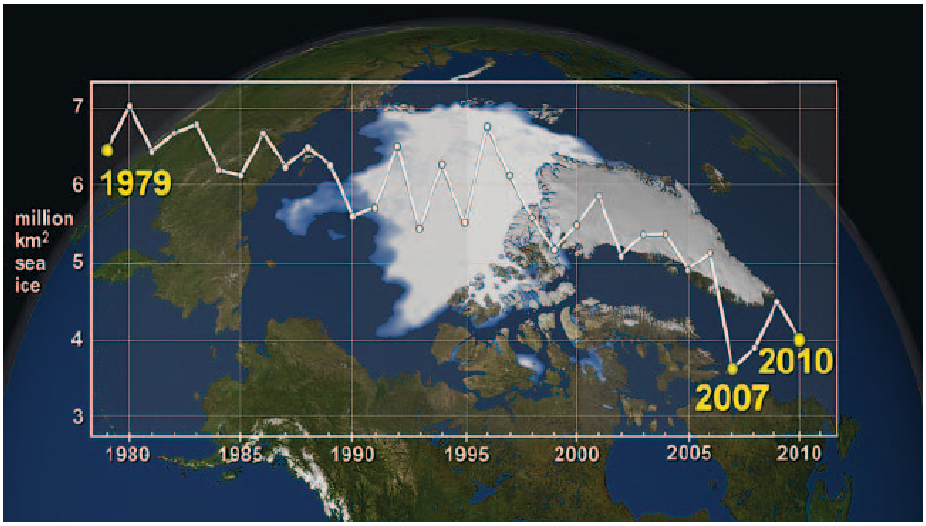


Figure 8.7. This graph shows the annual Arctic sea ice minimum from 1979 to 2010, highlighting the first dataset (1979), the most recent dataset (2010), and the lowest extent (2007). The graph is overlaid on a visualization that represents the annual Arctic sea ice minimum reached on September 17, 2010. Sea ice coverage in 2010 dropped to 4.6 million square kilometers (1.78 million square miles) at its minimum — lower than the 2009 minimum, but above the record minimums reached in 2007 and 2008. Credit: NASA/GSFC Space Flight Center Scientific Visualization Studio

The group has a strong heritage in using satellite data:

Heritage

- Major accomplishments in ice sheet, sea ice, and terrestrial snow research.
- Home of the ICESat and ICESat II missions.
- Research based on satellite visible/infrared imagery (specifically, AVHRR, MODIS, Landsat), satellite passive microwave data (specifically, the Scanning Multichannel Microwave Radiometer [SMMR], the Special Sensor Microwave/Imager [SSM/I], and the Advanced Microwave Scanning Radiometer-Earth Observation System [AMSR-E]) satellite radar and lidar altimetry (European Remote Sensing satellite [ERS]-1 and -2, ICESat).
- Research based on airborne visible/infrared, passive microwave, radar, and lidar altimetry instruments.
- Generation of algorithms and production of data sets for the community.
- Original development of passive microwave sea ice algorithms.

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Water and Energy Cycle, and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - ICESat II (Ice, Cloud, and Land Elevation Satellite–II) [timeframe: 2010–2013]
  - DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) [timeframe: 2010–2013]
  - LIST (Lidar Surface Topography) [timeframe: 2016–2020]
  - GRACE II (Gravity Recovery and Climate Experiment-II) [timeframe: 2016–2020]

Mass Balance and Water Storage in Ice Sheets, Ice Caps, and Glaciers

Our studies of Greenland and Antarctic ice sheets include mass balance, ice sheet dynamics, ice sheet history, and other glacier and ice sheet processes. This research requires extensive use of satellite data from radar altimetry, visible and microwave imagery, and, more recently, ICESat laser altimetry. Soon, ICESat II altimetry will provide enhanced new capabilities to measure polar ice cover. In addition, we have led the way in developing precise airborne survey capabilities to enable measurements of ice sheet topography and elevation changes over small ice caps, significant portions of Greenland, and some actively changing areas in Antarctica. These airborne measurements were the precursor to ICESat, and have also enabled verification of the satellite's data. By combining these activities with modeling and in-situ observations, we develop critical insights into the mechanisms that drive ice sheet and glacier behavior. Our glaciologists have uncovered the dynamics of dramatically changing ice streams in the West Antarctic and Greenland ice sheets, revealing new information about their behavior that has only recently been made possible by our remote sensing perspective. As a result, our scientists participate in and have led major international polar science programs, including the International Polar Year (IPY).

Our five-year primary focus in land ice activities will continue to be on determining how melt from Greenland and Antarctic ice sheets affects sea level in a changing climate. However, we will also work to assess the mass balance of the smaller ice caps and glaciers as a complement to these ice sheet studies, and will add staff to address ice sheet modeling needs. We will further strengthen our modeling capabilities to enable a comprehensive understanding of the changes in ice on Earth, applying this expertise as applicable to the ice cover on Mars or elsewhere in the Solar System in order to support other NASA initiatives. A major goal during the five-year period

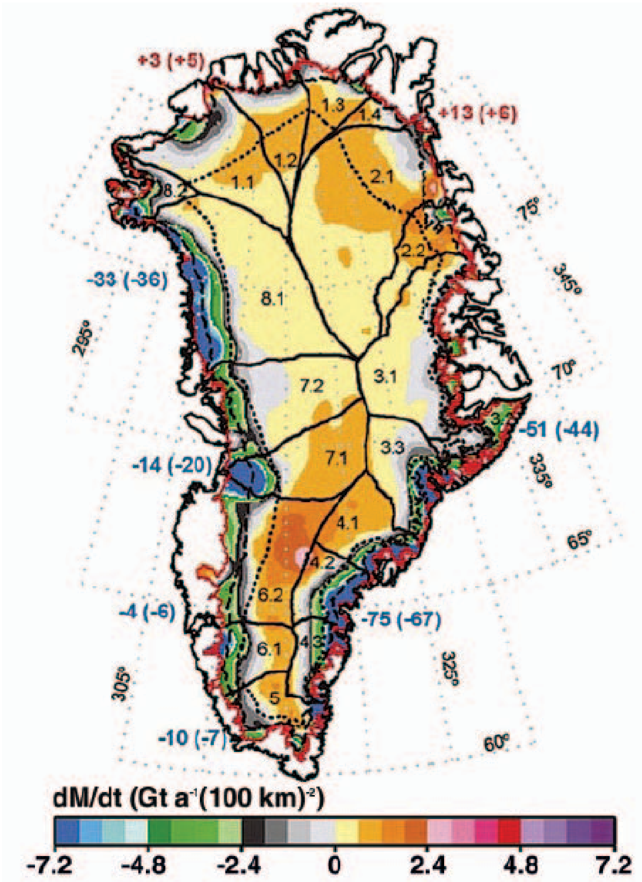


Figure 8.8. ICESat has allowed us to estimate the mass balance (dM/dt) for the Greenland ice sheet as well as for Antarctica. While there is a slight increase in mass in the center of Greenland, the margins of Greenland show a dramatic decrease (from Zwally et al., 2010).

is development of the ICESat II instrument and mission. In addition, we will extend our leadership in the analysis of ice sheet radar altimetry to include data on ice sheets to include advanced processing of data from the European Space Agency (ESA) CryoSat-2 mission to enable new insights into processes that are important for understanding ice sheet changes. Partnering with colleagues at JPL, we will be developing our experience with Interferometric Synthetic Aperture Radar (InSAR), and applying these capabilities to the studies of ice sheet morphology and dynamics.

In the upcoming five years, we will prepare ourselves for ICESat II, with GSFC as lead. GSFC cryospheric scientists provide the ICESat II project scientist and deputy project scientist, and several members of the ICESat II Science Definition Team. We will also seek participation in the upcoming DESDynI mission, as well as roles in the JPSS VIIRS and Defense Weather Satellite System (DWSS) microwave imaging/sounding (MIS), ESA's CryoSat, and the Japan Aerospace Exploration Agency (JAXA)'s Global Change Observation Mission-Water (GCOM-W), and GRACE II, as these latter two missions have sensors relevant to polar science.

In addition, by providing the project scientist and deputy project scientist, the GSFC group is leading the Operation IceBridge mission, an effort to bridge the data gap between ICESat and ICESat II by using airborne measurements over the Greenland and Antarctic ice sheets, as well as over sea ice. To find out how changes in Earth's polar regions may contribute to future sea level rise, scientists need to better constrain the predictive models; this requires a clearer picture of ice dynamics. Toward that end, mission planners carefully select targets most prone to change or where ice dynamics are not well understood. GSFC cryospheric scientists were also selected to serve as members of the IceBridge science team. Some flight lines are also coordinated with CryoSat-2 orbits.

The Role of Sea Ice in the Polar and Global Climate System

Sea ice, a key component of the ocean-ice-air system and a strong indicator of polar climate as well as global climate variability, is a major research topic within the Division. Our development and analysis of long-term sea ice records from passive microwave satellite observations has defined sea ice variability, including hemispheric, seasonal, and regional trends. Our scientists serve on the Aqua AMSR-E, Terra/Aqua MODIS, ICESat, ICESat II, GCOM-W, and AMSR2 Science teams, with responsibility for the sea ice algorithms and leading sea ice algorithm validation field campaigns. We have provided project scientists for Aqua, ICESat, and ICESat II.

Our analyses of satellite data and our numerical models of ocean-ice-atmosphere interactions address the dynamic and thermodynamic processes associated with sea ice variability. Other efforts focus on the sensitivity of atmospheric and oceanic variability to polar sea ice conditions and feedback mechanisms; specifically, the relationships between interannual to decadal oscillations and hemispheric sea ice and SSTs, the response of sea ice and ecosystems to warming trends in the Arctic, the relationships between sea ice motion and sea surface winds, and the role of Arctic and Antarctic coastal polynyas in deep-ocean water production.

Our five-year goals will include adding measurements and/or retrievals of sea ice thickness and snow on sea ice to our measurement capabilities. These measurements will allow us to monitor the third dimension of the sea ice cover, and will enable us to determine the sea ice mass balance. Technologies include ICESat, the ICESat II, and CryoSat-2, combined with radiometry from AMSR-E and other sensors and techniques, such as Synthetic Aperture Radar (SAR) and scatterometry. Adding staff to offset anticipated retirements, we will take advantage of our strength in passive microwave remote sensing to seek opportunities on missions led by organizations other than NASA such as DOD's DWSS or JAXA's Global Change Observation Mission – Water GCOM-W). We will also pursue utilization of active sensors, such as SARs and scatterometers. We plan to position ourselves to take advantage of the opportunities the Aquarius mission will offer to study processes of sea ice formation, sea ice melt, brine rejection, and their implications on ocean circulation. We will further develop the linkages between these new measurement capabilities and numerical modeling to understand the detailed interactions between sea ice and climate as satellite and model resolution and physics continue to evolve. Further, Operation IceBridge (mentioned previously) has a specific sea ice component to monitor sea ice thickness changes in the Arctic and Antarctic oceans, augmenting measurements originally established by ICESat.

Cryospheric modeling

The cryosphere is a key component in the GISS and GMAO coupled models, and provides key feedback for explaining past and current polar climate change. Improvements in sea-ice thermodynamics and dynamics are ongoing. GMAO has coupled the CICE model, developed at Los Alamos National Laboratory, into its coupled model. A new initiative, involving scientists from GSFC and GISS to couple the GLIMMER ice sheet model into the GISS and GMAO ESMs, is just starting, with ESD staff working in close collaboration with scientists at NCAR and DOE. There is a pressing need to tie credible estimates of ice sheet change to sea level and freshwater inputs in climate projections.

The group of cryospheric scientists at GSFC is one of the leading cryosphere research groups in the world. The field of cryospheric remote sensing especially has a very long heritage. Consequently, it has responsibility for providing a wide range of satellite expertise, algorithms, and geophysical products for current and future missions. While retirements in ice sheet science and remote sensing could be compensated for new hires, everyone in the field of sea ice science and, in particular, sea ice remote sensing is currently eligible for retirement. Thus there is a real danger in losing this expertise in the near future if no new scientists can be hired. A similar situation exists in scientists to explore the remote sensing of snow. New strategic hires in those fields are critically needed to retain the status of the cryospheric sciences at GSFC.

8.2.3 Terrestrial Water Cycle

The Terrestrial Water Cycle (TWC) is a fundamental component of the Earth system, with major impacts on human society and the biosphere, generally. GSFC has played an important role nationally and internationally in TWC research and applications by providing the unique space-based view of the Earth's water and energy cycles, as well as a unique terrestrial hydrologic modeling capability that merges these observations with predictive models. This leadership is largely a result of the presence of a critical mass of TWC scientists with a multi-decadal heritage of theoretical work, primarily in microwave remote sensing, instrument and algorithm development in collaboration with co-located engineers, numerous field campaigns for validation and technology advancement, hydrological systems modeling and data assimilation, and demonstration of the impacts of satellite retrievals on our ability to understand the behavior of the hydrological cycle.

The activities in this area deal with basic scientific questions:

Scientific Questions

- What are the causes of water cycle variations?
- Are variations in the global and regional water cycle predictable?

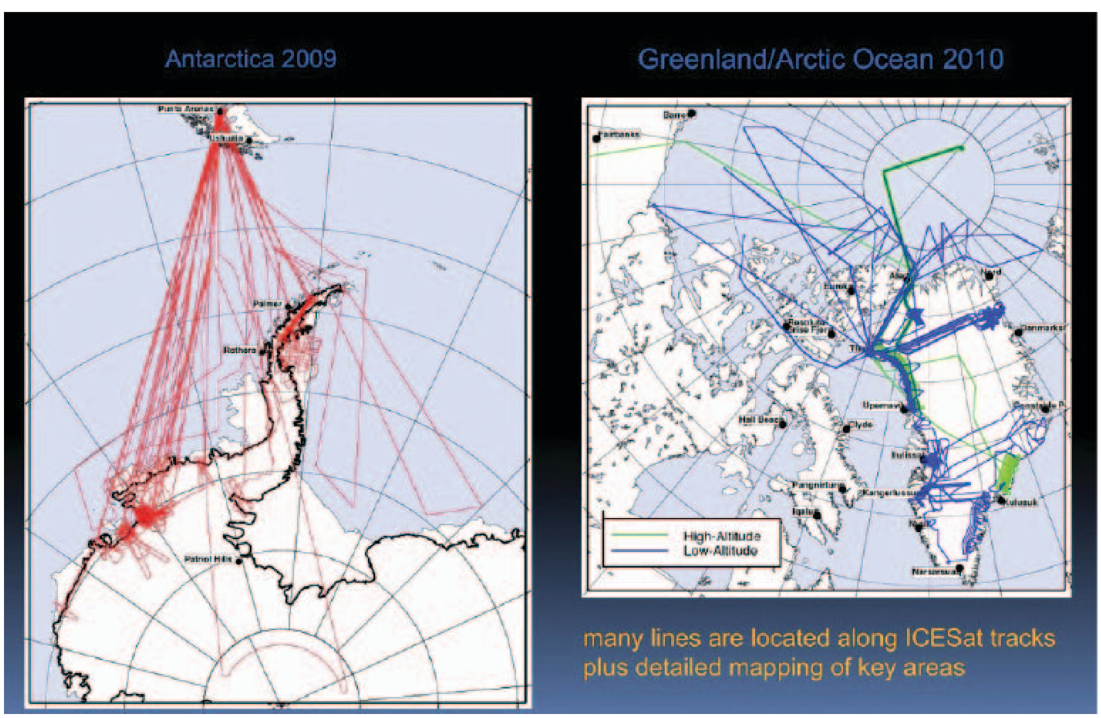


Figure 8.9. Flight lines covered by Operation Ice-Bridge in Antarctica 2009 and the Arctic 2010. Flight lines were selected to cover representative and/or critical areas with the intent to fly them repeatedly in order to continue to the timeseries of ice sheet elevation and sea ice thickness established by ICESat

- What is the impact of variations of snowmelt runoff on the availability of fresh water?
- How are water and biological cycles linked?

Heritage

- Historically, our research has been underpinned by:
  - Tropical Rainfall Measuring Mission (TRMM), Terra, Aqua (MODIS, AMSR-E, and AIRS) and Aquarius.
  - Production of long-term global soil moisture and snow data sets for climate change studies using SMMR on Nimbus 7, Landsat, SSM/I, AVHRR, and GOES.
  - Model development to describe long-term trends in ground water, large-scale evaporation over land, and atmospheric response to variations in the surface energy and water budgets.

The TWC activities are directly supportive of NASA priorities and are well-connected with the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Central to at least two of the six NASA Interdisciplinary Science Focus Areas: Water and Energy Cycles, and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - SMAP (Soil Moisture Active/Passive) [timeframe: launch in ~2015]
  - GPM (Global Precipitation Measurement) [timeframe: launch in 2013]
  - SWOT (Surface Water/Ocean Topography) [timeframe: 2013–2016]
  - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2018–2021]
  - GRACE II (Gravity Recovery and Climate Experiment-II) [timeframe: 2016–2020]
  - SCLP (Snow and Cold Land Processes) [timeframe: 2016–2020]

To be able to maintain the present commitments, to support Aquarius, and to participate in the design of the missions suggested by the NRC Decadal Survey, the Division proposes the hiring of two scientists.

Our terrestrial hydrology research strives to understand and predict all components of the terrestrial hydrological cycle over their broad range of spatial and temporal scales. This research therefore includes efforts to translate the remotely sensed measurements into geophysical properties such as soil moisture content, snow mass, precipitation, ground water, evapotranspiration, and vegetation density, and feed that information into land surface hydrological models. Key parameters in which we seek additional understanding are discussed below.

Soil Moisture

Soil moisture has been shown in model experiments to be a potentially important contributor to skill in the prediction of summer rainfall over continents. Soil moisture also plays a crucial role in vegetative processes, and it links the physical climate system (water and energy cycles) to biogeochemical cycles. Through numerous field and airborne campaigns, Division staff have convincingly demonstrated soil moisture remote sensing capabilities in terrain covered by thin or moderately dense vegetation (e.g., typical crops), using passive microwave emission radiometry at low microwave frequencies (1.4 to 3 GHz). This work has contributed substantially to the definition of the SMAP mission, a mission highlighted in the NRC Decadal Survey. SMAP will provide the first systematic measurements of Earth's changing soil moisture and of the freeze/thaw status of the land surface. Together, these measurements link the water, energy, and carbon cycles over land, and will open new frontiers in our understanding of how these global cycles interact in the Earth system. An immediate practical benefit of SMAP will be the improved accuracy of numerical weather prediction models that use the data.

Ground-water Mass

Division research uses space-based gravity gradiometer systems to measure changes in ground-water mass. These gravity field measurements are sensitive enough to detect the minute gravitational signature of the discharge/recharge of underground aquifers, as well as changes in soil moisture or snow water equivalent over continents. The current GRACE mission has demonstrated the ability to detect changes in mass distribution equivalent to ±1cm variation in water storage over a 500 x 500 km^2 area, with estimates validated against ground water wells and numerical ground water models. A recent *Nature* article documented dramatic declines in groundwater in Northern India, as shown in Figure 8.10. The five-year goal for this research includes implementation of the planned GRACE follow-on mission, which will provide the higher spatial resolution gravity measurement needed to resolve large basin aquifers around the globe. These measurements will provide important closure to basin-scale terrestrial hydrologic models. An additional staff member will be required to support this task.

Surface Water Storage and Discharge

The capability to coherently monitor inland waters is an essential future development of Earth-system models that monitor the biosphere and land-to-ocean linkages. Accordingly, a five-year goal is strong participation in the SWOT mission recommended by the NRC Decadal Survey for the 2013–2016 timeframe. This surface water mission will provide global surface water elevation, discharge, and lake storage information. This mission is expected to provide high-spatial-resolution data that can resolve the channels, floodplains, and lakes with a width of 100 m or greater that contribute most of a basin's discharge, high-temporal-resolution data that can capture short flood events, and precise vertical resolution that will measure the subtle height changes that can be responsible for significant discharge. The SWOT concept is based on an interferometric SAR, which will yield a water map of volumetric gain or loss after each overpass. It will enable hydrologists to move beyond the point-based gauging methods of the past century to measurements of the spatial variability inherent in surface water hydrology. Global coverage will ensure that, despite local economic and logistic problems, all countries could access measurements critical for forecasting floods and droughts, both of which have dramatic economic and human impacts. An additional staff member will be required to support this task.

Snow Cover and Water Storage

The snow research activity seeks to quantify the extent, storage of water, variability, and albedo of global snow cover. Our

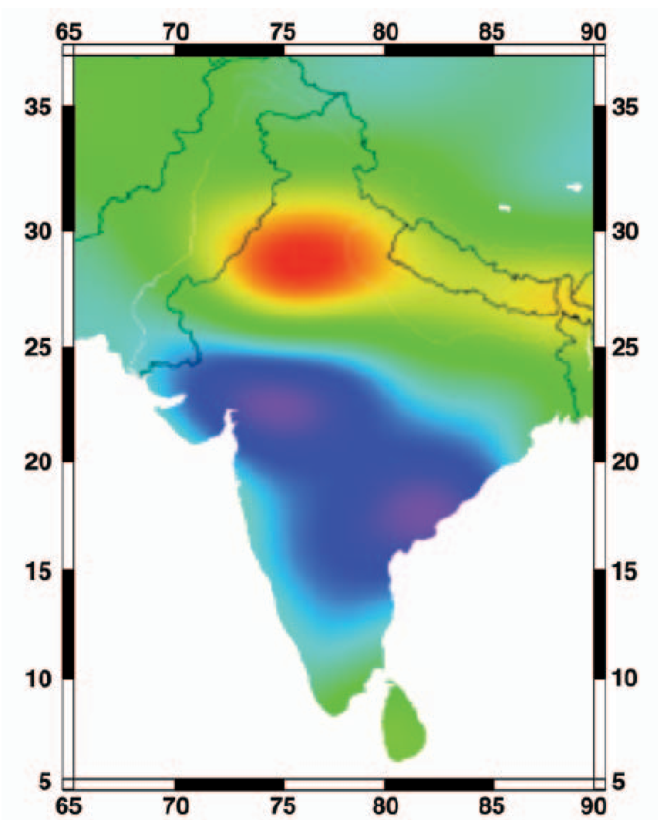


Figure 8.10. The map shows groundwater changes in India during 2002-08, with losses in red and gains in blue, based on GRACE satellite observations. The estimated rate of depletion of groundwater in northwestern India is 4.0 centimeters of water per year, equivalent to a water table decline of 33 centimeters per year. Increases in groundwater in southern India are due to recent above-average rainfall, whereas rain in northwestern India was close to normal during the study period.

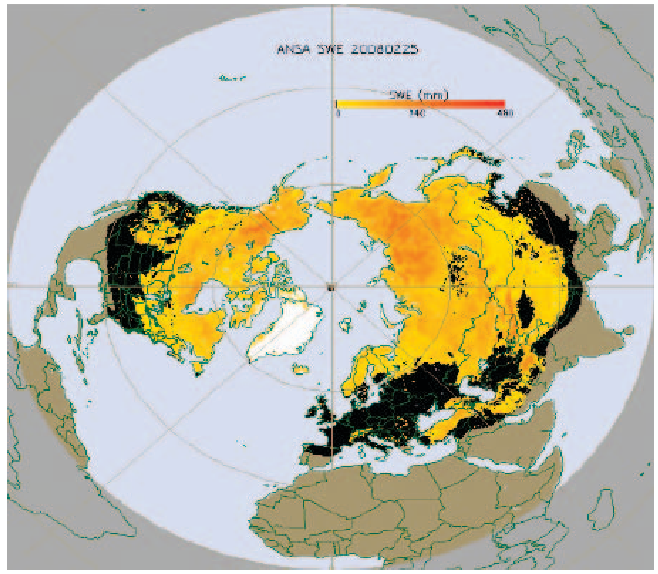


Figure 8.11. MODIS & AMSR-E snow maps are blended to create the Air Force - NASA Snow Algorithm (ANSA) snow product (funded by the U.S. Air Force. Shades of yellow represent different snow-water equivalents in each 25-km cell.

research on instruments and algorithms for passive-microwave sensors, visible/infrared (AVHRR and MODIS), has a five-year goal of providing all-weather global snow cover and Snow Water Equivalent (SWE) observation capabilities (see Chapter 8.6.1). Understanding the extent, timing, and nature of snow cover throughout the world is essential to determining its role in the climate system. The need for operational global SWE data on continental, regional, and local scales is based on the importance of runoff from snow melt in the water budget and hydrologic dynamics in many locations. Our strategy for improving our ability to measure and predict SWE and impact of snow on regional-scale hydrology supports our participation in the SCLP mission, which is a third-tier NRC Decadal Survey mission expected in the 2016–2020 timeframe. This mission concept combines active and passive microwave instruments to measure the snow pack. Laboratory scientists and others working in the Cold Land Processes Working Group are developing the SCLP concept. They are defining a comprehensive effort, which includes the Cold Land Processes Experiment (CLPX), and other community efforts. ICESat data is also being investigated for its application to snow thickness estimation.

Land Data Assimilation Systems

The full terrestrial and global water budgets are exceedingly complex, and not all components can be adequately measured. As a consequence, Land Data Assimilation Systems (LDAS) are used to combine the measurements with the physical constraints of the terrestrial water budget as well as other physical constraints. As shown in Table 8.4 in Chapter 8.6.1, a hierarchy of land data assimilation systems is currently being used across the Division depending on the analysis need, ranging from those that rely mainly on the integration of observed meteorological forcing (e.g., Global Land Data Assimilation System [GLDAS]) to those that use complex assimilation techniques (e.g., the ensemble Kalman Filter) to combine GLDAS-type integrations with satellite retrievals of surface state. The Land Information System is a computational framework that allows model integrations at scales down to 1 km. These systems provide new approaches to the analysis of diverse water cycle data sources—satellite-based precipitation, radiation, and surface parameters, in addition to model-derived surface meteorology—in a computer forecast venue. They support freshwater budget studies as well as a wide variety of applied uses. Our five-year goal is to continue improving our LDAS models, and to continue our close linkage with the research, observational, numerical weather prediction, and water resources applications (Chapter 10) communities. These models are maintained in such a manner as to enable parallel research activities with the other major land surface hydrology research laboratories around the nation. This will require continued improvements in our access to the high-end highly parallel processing support needed for the high-resolution numerical LDAS models.

Model Analyses of Hydrological Linkages

Hydrological research in the Division is not limited to the quantification of the means and variability of the water cycle's key components. Division scientists use the measurements and data assimilation products in conjunction with Earth system models to perform extensive sensitivity analyses of the mechanisms underlying water cycle connections, variability, and predictability. Such analyses are designed to quantify across a broad range of timescales how much predictability in the water cycle can be extracted from knowledge of initial water cycle state. In so doing, the analyses identify the quantities that require the most attention from NASA measurement systems in regard to predictive skill, not just which water cycle components should be measured most accurately, but also the critical regions and timescales over which these component's variations are most important.

Global Water Budgets and Variability with Climate Change

The combination of the many observations of water cycle components, together with our advanced assimilation systems, allows us to evaluate the contribution of each water cycle component to the full water cycle. In particular, we are greatly improving our understanding of how to measure the individual components and the relative importance of measurement improvements to error reduction in the quantification of the full cycle. Our five-year goal is to continue this research to the point that we can define the needed capabilities for a complete global water cycle observational analysis system. Development of such a system would enable us to observe and understand the global water cycle well enough to be able to predict variability due to changes in weather and climate. If we can do this, then we should be able to predict changes in the availability of clean water due to future global ecosystem changes, weather and climate variability, and human impacts including population growth. These water cycle questions address the fundamental ability of Earth to support life. Within this broad area of inquiry are fascinating and important science questions, the answers to which will help us understand our future prospects.

8.2.4 Atmospheric Water Cycle

The breadth and depth of Atmospheric Water Cycle (AWC) research at GSFC cannot be found anywhere in universities or other federal laboratories. AWC research performed at GSFC dates back to the late 1970s beginning with development of NOAA's Television Infrared Observation Satellites (TIROS) Operational Vertical Sounder (TOVS) to measure temperature and moisture. Cloud radiation research began in the mid-1980s with the inception of the International Satellite Cloud Climatology Project (ISCCP) and the launch of the ERBS (Earth Radiation Budget Satellite) satellite. The conceptualization and formulation of TRMM in the late 1980s in the Laboratory for Atmospheres and the launch of TRMM in 1997 have vaulted GSFC to become the preeminent world leader in precipitation research. This leadership role will be maintained as GPM is expected to provide multi-year, next generation, observations of global precipitation in the 2010 decade.

Our AWC research has a very strong record in both experimental activities and research and analysis, including: (1) strong in-house development of measurement technology such as precipitation and millimeter-wave cloud radars; lidars for water vapor, aerosols, clouds and wind; and cloud radiometers; (2) world class developments in cloud-resolving, mesoscale modeling, and multi-scale modeling framework (MMF or super parameterization and (3) the conduct of airborne and ground-based field campaigns for improved understanding of precipitation physics and measurement. The fine-resolution modeling approach, represented here, is especially and uniquely suited to the creative use of NASA satellite data to improve model physics, such as through application of the Goddard Satellite Simulator Unit (GSSU) to model fields and comparison to satellite observations at their observed scale. This should enable improved model simulations or forecasts through assimilation of satellite data.

Scientific Questions

- What are the causes of water cycle variations?
- How do clouds, water vapor, and precipitation processes affect regional-to-global weather and climate?
- What changes to the atmospheric water cycle are expected in a warmer global environment,

especially events with high impact on society, such as hurricanes, floods, drought, and forest fires?
- How can we use satellite measurements to better understand the physical processes of the atmospheric water cycle and to provide better representation of these processes in global climate and weather models?
- What are the fingerprints of climate variability and change in water isotope records?

Heritage

- The research in this area at GSFC began in the late 1970s with NOAA TOVS and Nimbus-7.
- AWC research continued through the 1980s with the ISCCP and the launch of the ERBS, as part of ERBE.
- TRMM was conceived of at GSFC and managed by GSFC throughout its lifetime.
- GPM was conceived of and developed at GSFC, and is also managed by GSFC.
- Extensive modeling efforts have been carried out at GSFC on the cloud scale, the mesoscale, and the global scale to study various processes affecting the AWC.
- GISS pioneered the use of isotope tracers in climate models, and remains in the forefront of this effort.

Relation to NASA Priorities and the NRC Decadal Survey

- Directly related to most of the six NASA Interdisciplinary Science Focus Areas. In particular, to the Weather, Water and Energy Cycle, and Climate Variability and Change.
- Directly related to the following missions recommended in the NRC Decadal Survey:
  - SMAP (Soil Moisture Active-Passive) [timeframe: 2010–2013]
  - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2018–2021]
  - PATH (Precipitation and All-weather Temperature and Humidity) [timeframe: 2016–2020]
  - 3D-Winds (Three-Dimensional Tropospheric Winds from Space-based Lidar) [timeframe: 2016–2020]

Central to the global water cycle are the space-based Precipitation Measuring Missions (PMM), beginning with the TRMM and continued with the GPM Mission. PMM provides not only state-of-the-art estimates of instantaneous and averaged precipitation, but also the phases of precipitation (liquid, frozen) and various products such as water vapor, cloud liquid water, cloud ice (from GPM), and vertical profiles of latent heating from the precipitation radar and the TRMM Microwave Imager (TMI). The CloudSat profiling radar is also used to investigate the microphysical properties of liquid- and ice-phase clouds. Combined with long-term records from ISCCP (see Chapter 8.6.1), the Earth Radiation Budget Experiment (ERBE), the High Resolution Infrared Sounder (HIRS), the Global Aerosol Climatology Project (GACP), and NOAA's TOVS, these measurements are critical in advancing understanding of fundamental aspects of the atmospheric water and energy cycle.

The inception and formulation of the TRMM mission in the late 1980s helped to focus the Division's precipitation research efforts; and as a result, GSFC has emerged as the preeminent leader in precipitation research. This leadership role will continue as new missions, such as GPM and NPP/JPSS are planned to provide continuous multiyear observations of precipitation to the end of the decade. The CALIPSO and CloudSat missions (launched in 2006) have provided unprecedented data to measure the vertical distribution of aerosols and cloud properties. A key focus of the ESD will be on the development of the Aerosols, Clouds, and Ecosystems (ACE) mission, which targets quantitative description of aerosol-cloud-precipitation-climate interaction at a fundamental physical process level. Our efforts include contributions in the area of instrument and algorithm development, specifically for polarimetry, advanced lidar and radar, and submillimeter radiometer, as well as microwave sensors. The ESD will also focus on the development of an advanced airborne wind lidar system and related technologies for water vapor transport in anticipation of the 3D-Winds mission from the NRC Decadal Survey. An ESD

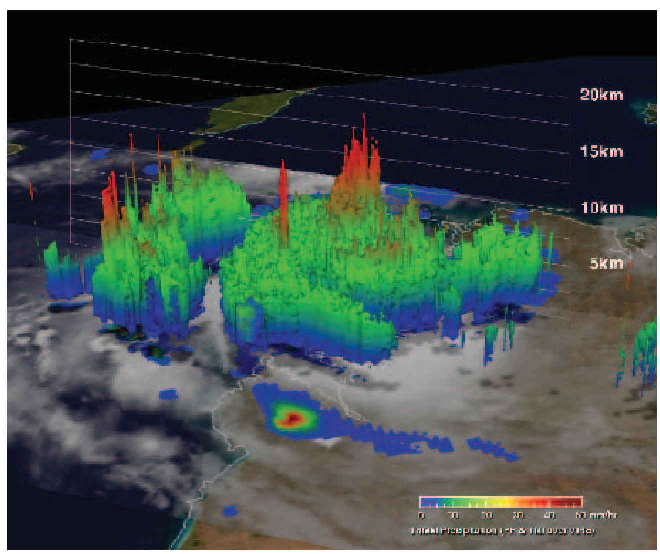


Figure 8.12. Image of tropical cyclone MAGDA on January 21, 2010, at 1927 UTC, constructed from TRMM PR, TMI, and Infrared (VIRS) data showing the three-dimensional iso-surface of the 15-dBZ radar reflectivity. The colors correspond to the vertical height (blue for the lowest altitude to red for tall thunderstorms indicative of future intensification). Also shown are surface rain rates in mm/hr superimposed on VIRS cloud.

priority is to promote close interactions with the international Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) as a means of translating cloud-resolving model information into improved global climate model parameterizations.

In the next five years, the overall objective of atmospheric water cycle research will be to determine the correlated time- and space-varying characteristics of precipitation, water vapor, clouds and aerosols, and associated atmospheric diabatic heating, and how these characteristics are related to variations and long-term trends in the overall water and energy cycles. The main thrusts of our research effort on atmospheric water cycle are:

Precipitation, Cloud, and Water Vapor Climatology, Variability, and Trends

We will continue to improve and employ novel approaches to combine satellite-derived precipitation information from multiple satellites in preparation for the eventual GPM rainfall products. GPM will observe precipitation from its core satellite with a dual-frequency precipitation radar and a microwave imager, together with a constellation of microwave radiometers on other platforms, to provide three-hourly global coverage. The multiple-satellite rain products will be used to validate model simulations of severe storms, to investigate spiral rainband structure in developing hurricanes, and to develop definitive climatologies of mesoscale convective systems in different regions around the world. GPM will also pursue precipitation products (as described in the next section) that assimilate satellite precipitation data into cloud-resolving models to provide observation-constrained high spatial and temporal resolution "dynamic" precipitation analysis for hydrological applications. The global precipitation data set listed in Chapter 8.6.1 represents the global monthly average precipitation estimates for the period January 1979 to the present. This data set is a major component of the Global Precipitation Climatology Project (GPCP), established to develop global precipitation data sets using satellite and conventional observations.

The possibility of TRMM continuing to fly for the next couple of years, narrowing or even filling the gap between TRMM and GPM (scheduled launch in 2013), has offered an exciting opportunity for a unique, intercalibrated, long-term global precipitation data set to better define the detailed diurnal and seasonal climatology of rainfall, and for determination of variability and trend in rainfall and water vapor as they relate to climate change. Moreover, the periodic overlapping observations by the TRMM and CloudSat radars, with sensitivities to different parts of the hydrometeor spectrum, are giving a more complete picture of global precipitation and precipitation processes in both liquid and ice phases. In addition to trend analysis of total rain, we will also focus on the long-term statistics of convective versus stratiform rain, cold-versus-warm rain processes, continental-versus-oceanic rainfall, mesoscale convective complexes, and their relationships with other components of the atmospheric water cycle (i.e., water vapor and sea surface temperature). In addition, GPM's focus on higher temporal and spatial sampling rates for global precipitation, especially solid precipitation over land and ocean in higher latitudes, will provide unprecedented global data not only on total precipitation, but also on rain types and hydrometeor characteristics. Such data products will be extremely important for precipitation research and for climate change impact studies.

Cloud variability and trends will be documented in the ISCCP, Clouds and the Earth's Radiant Energy System (CERES), and MODIS data sets. Analysis of radiative fluxes will enable observed variations in the planetary energy balance to be associated with specific cloud regimes and, thus, physical processes and feedbacks. The combination of TRMM latent heating profiles with ISCCP and CERES radiative heating profiles will create the first long-term record of total diabatic heating variations that force observed circulation anomalies on interannual and decadal time scales.

An important aspect of GSFC AWC research is the combination of a variety of datasets in order to understand the connections between cloud regimes, the dynamical/thermodynamical environment in which they form, and the precipitation and energy budgets with which they are associated. Advanced analysis techniques, such as conditional sampling, clustering, and neural networks, can be used to associate reanalysis data, such as the Modern Era Retrospective-Analysis for Research and Applications (MERRA), and a variety of energy and water cycle products, such as CERES and GPCP, with cloud regimes. Such an approach can provide new insights on the role of clouds in the hydrological and energy cycle, and serve as a guide for developing more innovative ways to evaluate climate models. Important outcomes of such an approach are identification of the meteorological conditions under which particular cloud regimes form, and assessments of the relative contributions of the various cloud mixtures to total precipitation and radiation fluxes.

Data Assimilation and Improved Climate Model Physics

Satellite rainfall, cloud, and water vapor products will be used for assimilation into the NASA GEOS-5 GCM and the community Weather Research and Forecasting (WRF) model for improving weather prediction and climate simulations. Unlike observations in clear-sky regions, rainfall data are difficult to assimilate because rain estimates from forecast models can have large biases. The PMM Science Team will provide leadership to the data assimilation community to explore innovative approaches to use rainfall data to improve atmospheric analyses and forecasts. These new approaches range from variational rainfall assimilation using the model as a constraint to super-ensemble forecasting techniques. In addition, new information on drop size distribution and cloud liquid water from TRMM/

GPM will provide more information on the rain microphysics and latent heating profile with regard to fundamental processes in the atmosphere such as diurnal cycle, and seasonal and intraseasonal variability. These processes need to be properly represented in order to increase reliability in long-term climate model projections. The resulting global analysis products will provide the most accurate estimates of long-term atmospheric circulation anomalies. They will be used to drive simulations of the column physics in climate models, which can then be directly compared to the satellite rainfall, cloud, and water vapor fields to evaluate the fidelity of parameterized model physics and to provide clues for model improvements.

Cloud, Precipitation, and Aerosol Interactions

Clouds and aerosols have been identified by the IPCC (2007) as two of the most crucial factors responsible for the uncertainties in model projections of climate change. The ESD has a long tradition of excellence in research of radiative transfer in clouds and aerosols. In the context of atmospheric water cycle, clouds and aerosols research are inseparable because aerosols modify clouds and rainfall (see discussion of aerosol/chemistry research in Chapter 8.1.2). In the near term, a major focus will be to conduct integrated satellite observation and modeling work over key regions, the so-called aerosol "hot-spots", where clouds and aerosols are expected to have large impacts on the water cycle. One of these is the Asian monsoon region, where aerosols from natural dusts and industrial pollution are increasing at an alarming rate, and where satellite analysis from MODIS, TOMS, TRMM, and field campaigns such as ACE-Asia and the Joint Aerosol Monsoon Experiment (JAMEX) have yielded some very promising results. Ongoing and future measurements from the Seven South East Asian Studies (7-SEAS) multi-year campaign and the planned NASA SEAC4RS field campaign will provide additional insights. Other areas of research include the effects of biomass burning in the Amazon and other areas in South America, Saharan dust on the West African monsoon, and possible effects on rainfall and tropical cyclone geneses over the tropical Atlantic and their impacts downstream in the Caribbean, and the Southeast United States. Research also focuses on floods and droughts in the North American continent, especially the Midwest and Southwest United States. A new interdisciplinary research focus is also being pursued on the possible impacts of black carbon, dust, and other aerosols on the accelerated melting of snowpacks in the Himalaya-Tibet regions, and their ramifications for changing long-term rainfall patterns and supply of fresh water in Asia. These studies are focused on the interaction between aerosols-cloud-precipitation, radiation, and dynamics as prime drivers of the regional and global water cycle. The results will, in turn provide a context for understanding observed multi-decadal variability in the interactions between GACP aerosol (MODIS, GAC), cloud and radiative fluxes (CERES, ISCCP), and precipitation (GPCP, TRMM, GPM). Glory APS retrievals will be used to quantify the role of composition and microphysics of aerosols on the aerosol effect on clouds and precipitation. We will continue to develop innovative measurement technology of lasers and lidars, radars for clouds, aerosol and rainfall measurements to augment and calibrate data from planned satellite missions such as Glory and ACE including instruments for ice clouds, such as using a submillimeter radiometer, and a 3D Cloud-Aerosol Interaction Mission (CLAIM-3D) for lateral viewing of cloud-aerosol microphysics. We will also maintain the strong collaboration with the Department of Energy (DOE) Atmospheric Systems Research (ASR) program, which now includes what was previously known as the Atmospheric Radiation Measurement (ARM) programs.

Integrated Observations and Modeling

In addition to the aforementioned GEOS-5 global modeling effort on precipitation, clouds, and aerosol (see also Chapter 8.1.1.2), modeling activities for the atmospheric water cycle will focus on the improvement of cloud microphysics, using cloud-resolving models, such as the GCE model and large-scale eddy simulation models to take advantage of the high-vertical-resolution data from TRMM, GPM, CALIPSO and CloudSat and other planned satellite missions. Modeling activities will be focused on improving the representation of atmospheric hydrologic processes, including clouds, precipitation, radiation, and aerosols, in climate models. Plans for improved cloud representation in models includes the capability of treating horizontally inhomogeneous clouds with arbitrary overlap and the prediction of cloud particle numbers and sizes; radiation improvements that focus on increasing the spectral resolution for improved calculations of gaseous absorption and forcing; and aerosol improvements that include information about mixing and size distributions of different species. Experiments, in comparison to observations, will be carried out to evaluate the ability of models to simulate fundamental phenomena such as the diurnal, seasonal, natural, or anthropogenically induced water cycle changes. As high-performance computing resources continue to increase, the multi-scale modeling framework (MMF), where cloud-resolving models are embedded into climate models, will be further developed and used to study the clouds and their impact on atmospheric water cycle associated with short-term climate and weather. A parallel strategy is the development of a global non-hydrostatic, cloud permitting/resolving GEOS-6 model to study scale interactions in global water cycle processes. The integrated observation and modeling research will also be carried out in conjunction with IPCC assessments and climate model projections, infusing advanced diagnostics and better usage of NASA satellite data in IPCC model intercomparisons, and validation studies.

Coupled Modeling System and Satellite Simulators

During the past five years, a multi-scale modeling system with unified physics was developed at GSFC. It consists of (1) the Goddard Cumulus Ensemble model (GCE), a cloud-resolving model (CRM); (2) the NASA Unified Weather Research and Forecasting Model (NU-WRF), a region-scale model; and (3) the coupled fvGCM-GCE, the GCE coupled to GMAO's finite-volume general circulation model (MMF). The same cloud microphysical processes, long- and short-wave radiative transfer, and land-surface processes are applied in all of the models to study explicit cloud-aerosol-radiation and cloud-surface interactive processes in this multi-scale modeling system. Since the MMF can explicitly simulate cloud processes at the natural space and time scales of cloud-dynamical processes; cloud statistics, including radiances and radar reflectivities/attenuation, can be directly extracted from the CRM-based physics embedded within the MMF and compared against measurements. The MMF is a promising a new pathway for using NASA satellite data to improve our knowledge of the physical processes responsible for the variation in global and regional climate and in hydrological systems.

This modeling system is being linked to GSFC satellite data simulator unit that can convert model simulated cloud and atmospheric quantities into radiance and backscattering signals consistent with those observed from NASA satellites. The satellite simulator serves a bridge between high-resolution model results and satellite observations. It can be used to formulate a radiance-based evaluation method, including active sensors such as lidar and radar, for clouds and precipitation simulated from numerical atmospheric models. It directly supports radiance-based data assimilation for numerical atmospheric models, and supports formulations and algorithm development for current and future NASA satellite missions (e.g., A-Train constellation, GPM, and ACE) by providing virtual satellite measurements as well as simulated geophysical parameters to satellite algorithm developers.

Currently, this modeling system and satellite simulator are being coupled with GOCART (see Chapter 8.1.1.2), and the land information system (Chapter 8.2.3). In the next two-to-five years, the coupled modeling system will be coupled with GEOS5, and ocean model. The CRM-based cloud microphysics and its interactions with radiation and surface processes will be implemented into a high-resolution, non-hydrostatic, global cloud-resolving model. The modeling and satellite simulator development and improvement are closely coordinated with the GMAO (Chapter 8.4), GOCART (Chapter 8.1.1.2) and LIS (Chapter 8.2.3).

Applications

We will enhance our effort in areas with potential applications to rainfall and water resource distributions. We will provide real-time data from NASA satellites, such as TRMM, GPM, and AIRS, and collaborate with scientists from other agencies to improve skill of numerical weather forecasts. Near real-time TRMM and GPM-based estimates of tropical cyclones, flood warnings, and landslide potentials will be provided to various disaster-relief agencies in the U.S. and overseas where conventional information is lacking. We will collaborate with NOAA's National Environmental Satellite Data and Information Service (NESDIS) to provide rainfall data to estimate flood potential in hurricanes. NASA's TRMM and GPM Multisatellite Precipitation Analysis 3-hourly global rainfall data sets will be made widely available to assist in the detection of floods and the monitoring of rain for agricultural uses.

Building upon the Center's internationally acknowledged leadership in space-based precipitation measurement, analysis, and applications, GSFC will spearhead the research and development of high-resolution global precipitation data products that combine space and ground-based measurements within a rigorous framework of statistical estimation. In taking on this ultimate challenge in providing the best possible global precipitation estimates for scientific discovery and societal applications, GSFC will embrace high-priority research in the following areas: (1) advanced precipitation remote-sensing algorithms to maximize the information content in GPM radar and radiometer measurements, (2) methodologies and field observations to quantify and characterize uncertainties in space and ground-based precipitation estimates, (3) innovative analysis techniques for merging precipitation measurements at different spatial and temporal resolutions, and (4) dynamic downscaling of satellite precipitation information using cloud-scale mesoscale models for hydrological applications over complex terrains. Key to our future success is:

1. Leadership and expertise in developing a state-of-the-art multi-satellite algorithm to support the launch of the GPM Core Observatory in 2013 (Huffman);
2. Innovation and expertise in remote-sensing algorithms that optimize information from combined GPM radar/radiometer measurements to advance instantaneous precipitation estimation from space, especially for light and solid precipitation over land (Munchak); and
3. Leadership and expertise in processing and quality control of precipitation data from international networks of ground radars/gauges to facilitate the development of variable-resolution global precipitation data products using combined satellite/ground-based measurements (Kidd).

In addition, it is also essential that we maintain our pre-eminent position in areas of cloud and precipitation radar system development and science application (successor to Gerry Heymsfield, who is eligible for retirement), and microwave and submillimeter radiometer development and science (replacement for Jim Wang, who has retired). Lastly, given NASA's strong investments and our great success at cloud system modeling and the science application of that via cloud-resolving models, NU-WRF and MMF, it is a high priority to hire and develop additional staff in this area. Our cloud modeling is connected in a highly productive way to science efforts across the directorate. At present, we have a single PI who leads the development, with no successor in the wings. We should definitely position ourselves to maintain our present leadership in this area.

8.3 Carbon Cycle and Ecosystems

The Earth's carbon cycle is a key evolutionary component of Earth's biology and climate. Unfortunately, our knowledge of Earth's carbon budget is currently missing some significant components of carbon absorption or emission. Therefore, a key carbon cycle objective is to close the carbon cycle budget through reducing the uncertainties in its atmospheric, land, and oceanic components. Disturbances by natural phenomena, such as fire, wind, or by human activities, such as forest harvest and subsequent recovery, complicate the quantification of carbon storage and release. The spatial and temporal heterogeneity of terrestrial biomass makes it very difficult to estimate terrestrial carbon stocks, and quantify their dynamics. It is thus imperative to learn more about less-studied components of the carbon cycle, including soil carbon, the impacts of thawing permafrost, changes in wetlands, feedbacks with climate, and the roles of human activities.

Carbon cycle and ecosystems research at GSFC consists of terrestrial carbon cycle measurements and modeling (including terrestrial ecosystems, land cover, and land use change), marine phytoplankton measurements and monitoring, atmospheric CO_2 transport models (with links to terrestrial and oceanic sources and sinks), and oceanic sources and sinks, and atmospheric circulation models with links to surface properties. A major component of our research relates to satellite data information systems and assimilation of satellite carbon cycle observations into weather and climate models. GSFC is also a leader in lidar technologies that allow for critical measurements of vegetation structure and biomass, of land and ocean ecosystem characteristics, and of atmospheric CO_2 measurements.

The GSFC Carbon Cycle and Ecosystems group addresses these scientific questions:

Scientific Questions

- How are the Earth's carbon cycle and ecosystem changing?
- How will climate change influence carbon cycle, ecosystem sustainability, and biodiversity?

Heritage

- Early development and demonstration of global vegetation analysis from satellites.
- Development and refinement of the coupled carbon cycle-climate models (Simple Biosphere Model version [SiB2])
- Development and validation of global land vegetation data records from Landsat, AVHRR, and MODIS.
- Development and validation of ocean color data sets from SeaWiFS and MODIS.
- Sensor calibration and characterization to support Landsat from its inception and into the Landsat Data Continuity Mission (LDCM), MODIS, and VIIRS eras.
- Scientific support for SeaWiFS, the Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS), MODIS (Aqua and Terra), ICESat, NPP, Earth Observing (EO)-1, ICESat, and Spaceborne Imaging Radar (SIR)-C science.
- Development of lidar and radar techniques for vegetation structure and biomass assessment.

The activities of the carbon cycle and ecosystems group are directly relevant to NASA Headquarters' priorities and to the missions proposed by the NRC Decadal Survey as outlined below:

Relation to NASA Priorities and the NRC Decadal Survey

- Carbon Cycle and Ecosystems is one of the six NASA Interdisciplinary Science Focus Areas. In addition, the activities of this focus area relate well with the Water and Energy Cycle and the Climate Variability and Change themes.
- The Division has opened an office to support the new NASA Carbon Monitoring System effort.
- GSFC will compete to be the lead center for the PACE mission and will propose ORCA as the ocean radiometer.
- Our Carbon Cycle and Ecosystems research is directly relevant to the following missions recommended by the NRC Decadal Survey:
  - SMAP (Soil Moisture Active Passive) [timeframe : 2015]
  - ICESat II (Ice, Cloud, and Land Elevation Satellite–II) [timeframe: 2015].
  - HyspIRI (Hyperspectral/IR Imagery) [timeframe: 2020].
  - ASCENDS (Active Sensing of CO2 Emissions over Nights, Days, and Seasons) [timeframe: 2020].
  - GEOCAPE (Geostationary Coastal and Air Pollution Events) [timeframe: 2020].
  - ACE (Aerosol-Cloud-Ecosystem) [timeframe: 2018–2021].
  - LiST (Lidar Surface Topography) [timeframe: 2020].

The Division proposes the hiring of five scientists to allow us to maintain the present commitments, to support DESDYnI, SMAP, ICESat II, NPP, Landsat Data Continuity Mission, and to participate in the design of other missions suggested by the NRC Decadal Survey.

The largest and best understood of the factors that contribute to climate warming is the rapid and continuing increase in atmospheric concentrations of "greenhouse" gases. These are trace gases that are transparent to the Sun's shortwave radiation but absorb longwave radiation emanating from the Earth's surface, thus warming the atmosphere. CO_2 released by fossil fuel combustion and landcover change such as deforestation is the most rapidly increasing greenhouse gas, and the one that is widely accepted as the largest contributor toward warming of the Earth's climate. On average, about half the CO_2 released into the atmosphere through human activities each year remains there, steadily increasing atmospheric CO_2 levels, now over 380 ppm, and is more than 35 percent above the maximum levels of the past 400,000 years. The other half is being taken up by the Earth's oceans, and land ecosystems, and direct atmosphere-ocean exchange. There is much uncertainty as to the locations and mechanisms that take CO_2 out of the atmosphere and provide the service of ameliorating the increase in atmospheric CO_2. Will these sinks for CO_2 continue to operate in the future? Or, will they reverse and aggravate the greenhouse warming trends?

Answering this question is a scientific imperative of this century. Until we can locate these sinks and sources for CO_2, quantify their strengths, and understand their biological and physical mechanisms, predictions of future atmospheric CO_2 concentrations and, hence, climate change, will be unreliable. The U.S. Climate Change Science program has identified a number of specific science questions focused on addressing the carbon sink issues:

1. What are the magnitudes and distributions of North American carbon sources and sinks on seasonal-to-centennial time scales, and what are the processes controlling their dynamics?
2. What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal-to-centennial time scales, and what are the processes controlling their dynamics?
3. What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?
4. How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal-to-centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?
5. What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?
6. How will the Earth system and its different components respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

8.3.1 Terrestrial Carbon Cycle

The uncertainties in carbon stocks and fluxes of carbon are much larger for the land than for the atmosphere and oceans. A number of mechanisms have been proposed to explain the inferred land sinks, including biomass accumulation due to land use activities and the responses of ecosystems to climate change. Satellite remote sensing has contributed critical information leading to new insights, and represents the most promising approach for further improvements in understanding and monitoring the terrestrial carbon cycle.

ESD's terrestrial carbon cycle scientists have strong connections with the larger carbon cycle science community, and participate in investigations of the terrestrial carbon cycle at scales from short-term local to long-term global. Using existing satellite resources (e.g., AVHRR, MODIS, Landsat, ICESat, ALOS PALSAR), airborne instruments, and extensive field studies, Division members have developed indicators of vegetation activity, land surface carbon stocks, land disturbance, and fire activity (Figure 8.12). Division members are using computer models driven by remote sensing data to understand the process controlling ecosystem productivity and carbon fluxes over the past two decades. The advances gained from understanding recent phenomena are being used to improve model forecasts. Collaborations within the ESD include the modeling of atmospheric carbon and the development of a unified land surface model with coupled water, energy, and carbon cycles, to address terrestrial carbon cycle studies. Paleovegetation studies have helped the understanding the interplay between vegetation dynamics, climate change, and the carbon cycle. Particularly important is the role of soil carbon, which represents two-thirds of the terrestrial carbon storage, and is accumulated over very long time scales. The carbon stored in currently frozen soils is especially important; understanding its dynamics is an important research goal for the future. Future development plans include field, aircraft, and satellite measurements, combined with coupled modeling and an assimilation system to quantify air-land and air-ocean carbon fluxes.

Scientists in ESD are working closely with scientists and engineers in the Solar System Exploration Division to develop laser technologies that can be flown in space and can be used to measure carbon stocks in vegetation and in the Earth's atmosphere. For example, the laser planned for use with DESDynI lidar mission (High-Output, Maximum Efficiency Resonator [HOMER]) has been developed over several years.

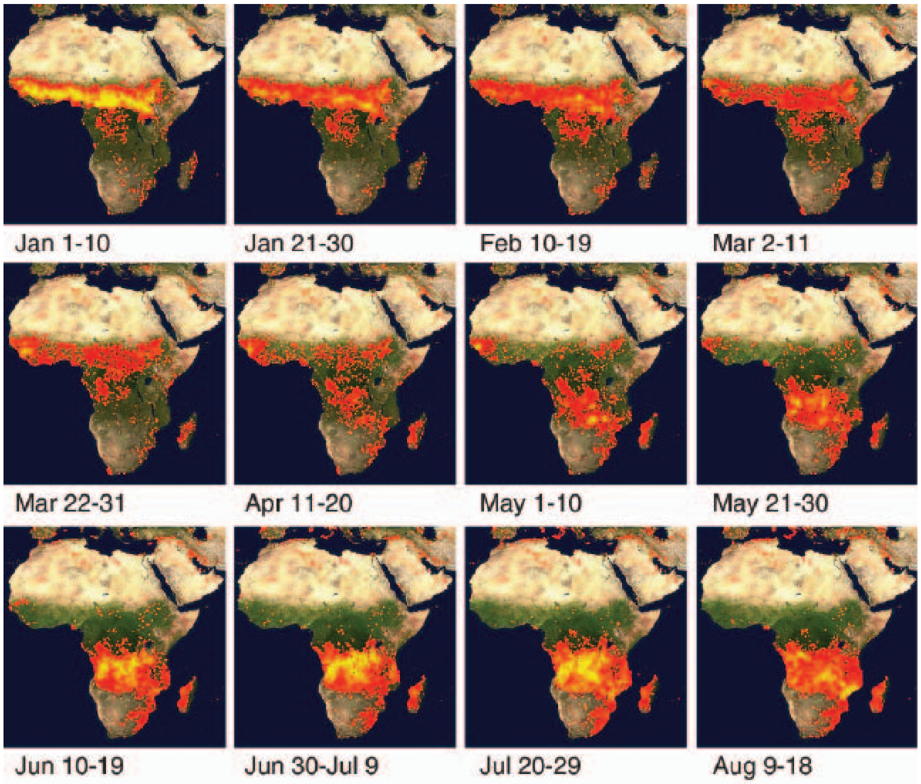


Figure 8.13. This series of images shows the seasonal fire patterns in Africa throughout 2005. The images are based on fires detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites. Each image is a composite of 10 days of fire detections (marked in red and yellow) made by the sensors. The series includes images from every other 10-day period from January 1 through August 19, 2005.

ESD scientists have been using data from the airborne version of this lidar to advance scientific understanding and develop suitable algorithms. Recently the HOMER laser completed 6.9 billion firings representing the full lifetime of the DESDynI mission plus a 30 percent margin, with minimal degradation. The need for these capabilities is explicitly addressed in the NASA Headquarters Roadmap for the Carbon Cycle and Terrestrial Ecosystems Program.

In the next five years, we plan to ensure continued advances in carbon cycle research which include:

- The development of a coupled model and assimilation system to quantify air-land and air-ocean carbon fluxes;
- The study of the variability of trace gases in the atmosphere and their dependence on biomass burning and land cover change;
- Development of global disturbance maps at fine spatial resolutions (50 m–1 km);
- Development of new techniques and algorithms to measure vegetation structure and functioning using new instruments on aircraft and space platforms, and development of new ways of analyzing EOS long-term data sets for the purposes of extracting carbon cycle-related information;
- The development of new carbon-related missions—such as DESDynI—under NASA's Earth Science and Application decadal survey; and
- The development and science support for accurate ocean productivity measurements.

8.3.2 Terrestrial Ecosystems and Land Cover

Land Cover describes the distribution of vegetation and land types around the globe. It provides the lower boundary condition for atmospheric transport, and mediates biochemical exchange between the atmosphere and hydrosphere. In addition, because human populations live on the land, human appropriation of Earth's environment for food and fiber can be directly observed through changes in land cover, such as deforestation, urbanization increases in irrigated agriculture, etc. Land cover and land use change occur over a large range of temporal and spatial scales. For example, boreal fires typically mark the landscape at scales of up to a few 100 km^2, human-driven disturbances in third-world countries often individually occur at sub-hectare spatial scales. However, when these disturbances are aggregated to regional scales, they frequently represent large impacts on the carbon cycling, hydrology, and resources. The rates at which these changes occur fluctuates with climate and politico/socio/economic conditions, and long-term trends in land cover changes can significantly affect climate and the sustainability of resources needed to support human populations and natural ecosystems. It is for these reasons that the study of land cover and its changes often requires fine-spatial-resolution measurements over decades. Space-based observations are the only plausible method of monitoring land cover change processes at continental-to-global scales in a consistent way over annual-to-decadal time periods.

The Division has a long and productive history of developing satellite measurement concepts and of validating satellite data algorithms that can map land cover change over the entire period of record of land satellites. These capabilities have permitted us to map changes in ecosystems from regional-to-global scales. The Division is also engaged in modeling ecosystem processes and patterns in response to natural and anthropogenic effects. This research uses coupled ecosystem models and remote sensing observations to monitor and predict ecosystem change in a variety of vegetated systems: boreal, tropical, temperate, and semi-arid. Monitoring land cover change using satellite imagery reveals the extent and rates of natural and anthropogenic impacts on vegetation. The data for these studies come from Landsat, EO-1, Defense Meteorological Satellite Program (DMSP), and the NOAA polar-orbiting operational satellites. The Division plays a leading role in Landsat and EO-1. In fact, we are hosting the Landsat Project Science Office (LPSO), which is responsible for ensuring the long-term science integrity, including sensor calibration. Using high-resolution imagery, forest disturbance is being mapped across North America using decadal Landsat imagery as part of the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). A new project is focusing on correlating long-term trends in North American vegetation indices with changes in land cover, to separate climate-driven trends from human activities. Forest-cover change and disturbance are also being mapped in North America and northern Eurasia.

Over the next five years, questions of terrestrial ecosystem change and movement and of land cover change will be addressed by combining data from multiple sensors, both for current and for long-term analyses. The Division's unique capabilities for modeling electromagnetic energy interactions with vegetation will be exploited for this purpose. In addition, analyses of Landsat and higher-resolution data sets will facilitate the understanding of regional-to-global ecosystem processes. We look forward to having global coverage capability early in the next decade for continuing our assessment of decadal global land cover change. We also expect that over the next decade, there will be an evolution from analysis of land cover change to monitoring of ecosystem functioning in terms of productivity, stress, and structure. New technology will be required to accomplish this. For example, imaging spectroscopy in both low Earth and geosynchronous orbits, and imaging lidar can provide the fundamental measurements required. To meet these needs, we are heavily involved in the NRC Decadal Survey HyspIRI, GEOCAPE, DESDynI, and several Venture Class mission concepts.

The Carbon Cycle and Ecosystem area of research is a vital and growing area within the Division. Accomplishments for 2010 include:

- Project Science support for all missions: Landsat Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), EO-1, EOS Terra/Aqua/Aura, LDCM, NPP, JPSS, DESDynI, CLARREO, HyspIRI, ICESat II, SMAP, ASCENDS, Glory, PACE, and GOES-R.
- Science support of DESDynI and CLARREO NRC Decadal Survey missions leading to successful Mission Concept Reviews.
- Hired three early-career scientists.
- Trained numerous graduate students and participated in minority university technical review panel.
- Successful IRAD proposals, including GLght [multiple sensor package from light aircraft], Radio Frequency Plasma Discharge Lamps as Stable Calibration Light Sources, Nanotubes for Stray Light and Diffraction Suppression (IRAD Innovator of Year Award winner).
- Successful IIP Ecological Structure Activity Relationships (ECOSAR) proposal.
- Leadership of the Carbon Cycle and Ecosystem Office.
- Coordination of the North American Carbon Program.
- Initiated the Carbon Monitoring System project.
- Conducted field and aircraft campaigns to support R&A projects in the United States, Canada, and Russia.
- Completed four-year collaborative study in Norway for forest ecosystem structure with lidar.
- Supported Baltimore-Washington Partnership for Forest Stewardship.
- Supported the United Nations Climate Change Conference (COP16) in Cancun, Mexico.
- Leadership of the Florida International University Minority University Research Center technical review panel.
- Hosted Ecosystems Product Workshops for HyspIRI at GSFC.
- Performed field calibrations at NASA Ames (the MODIS/Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) airborne simulator - MASTER) and the University of Lille (AERONET and other projects) and lab calibrations at GSFC for a number of satellites (e.g., NPP OMPS and VIIRS, ICESat II), airborne (e.g., Research Scanning Polarimeter and Airborne Compact Atmospheric Mapper) and ground-based (e.g., AERONET, Normal Incidence Pyrheliometers [NIP], Precision Spectral Pyranometers [PSP], Pandora 1 and 2) instruments.
- Measurements of Bidirectional Reflectance Distribution Function (BRDF) of carbon nanotubes by the Diffuser Calibration Facility Calibration leadership for Landsat (OLI and TIRS), EO-1, Terra, LDCM, NPP, JPSS, and CLARREO.

Our near-term goals begin with ensuring data continuity for coarse-resolution (1 km) and higher (30 m) sensors. These long-term, systematic measurements include data continuity from AVHRR to MODIS to VIIRS on NPP and on JPSS. Higher-resolution data continuity resides in the Landsat series. Division efforts are required to ensure that this long-term record continues and that it is appropriately calibrated and validated to ensure that science goals are attained. For coarse-resolution data, efforts will continue with MODIS on Terra, and work on the NPP Project Science and NPP Science teams. For Landsat, a data gap looms with the failing health of Landsat 5 and Landsat 7; the near-term future launch of LDCM should fill this potential void. We have already begun discussions concerning development of Landsat-9 to follow LDCM.

Specific goals for 2011 include:

- Conduct airborne and field measurements campaigns for DESDynI, ECOSAR, and FUSION.
- Provide science leadership for DESDynI and CLARREO as they move into Phase A.
- Continue project science support for missions.
- Provide support for Landsat (OLI and TIRS), EO-1, Terra, LDCM, NPP, JPSS, DESDynI, CLARREO, HyspIRI, ICESat II, SMAP, ASCENDS, and SWOT.
- Provide calibration leadership for Landsat (OLI and TIRS), EO-1, Terra, LDCM, NPP, JPSS, and CLARREO.
- Provide applications leadership for SMAP, ICESat II, SWOT, DESDynI, and the Carbon Monitoring Mission.
- Provide leadership of the Carbon Cycle and Ecosystem Office.
- Provide coordination of the North American Carbon Program.

8.4 Climate and Weather – Analysis, Modeling, Assimilation, and Prediction

The linkage across the disparate fields of atmospheric, hydrological, and biospheric sciences transcends the disciplines: atmospheric prediction models need oceanic and land surface boundary conditions, ocean models need atmospheric wind stress, biospheric models need rainfall, etc. These interface requirements require development of interdisciplinary climate and weather prediction models. Ultimately, the interfaces must be represented within a completely integrated model—coupled ocean, atmosphere, land, sea-ice, chemistry, and biosphere—with the system components fully interactive for a consistent representation of the Earth as an integrated system. Within the ESD, the weather and climate forecast groups link the other disciplinary activities, and are the vehicle for the development of this integrative Earth system model and an accompanying assimilation system—one of the major five-year goals of the Division.

NASA's role in weather and climate modeling is based on our mission to do remote sensing from space and to develop the data analysis algorithms that provide observations needed to understand the Earth system as a whole. It is only through this that we can understand the effects of natural and human-induced changes on the global environment. Though this, NASA and NOAA are united in their common reliance on access to and use of global satellite data to achieve their goals.

Since NASA has been one of the primary sources of information concerning global climate variability and change, our modeling efforts focus on the development of state-of-the-art Earth System Models (ESMs) in addition to weather modeling and assimilation. To address the cross-disciplinary nature of weather and climate modeling, the Division has two very active groups: one at GISS, which focuses on long-range climate modeling, and one in the GMAO, which focuses on data assimilation and weather and climate prediction on subseasonal-to-decadal timescales. These groups have active collaborations throughout the Earth Sciences Division to address cross-disciplinary science questions. For example, GMAO collaborates with ACDB in the development of the GEOS CCM (see Chapter 8.1.1.2) and the integration of aerosol models into GEOS-5. To achieve our climate modeling goals, Division scientists also have strong collaborations with NOAA's National Center for Environmental Prediction (NCEP), the National Center for Atmospheric Research (NCAR), NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), and DOE's modeling efforts.

GSFC has provided leadership for NASA's modeling and data assimilation capabilities in support of weather and short-term climate research for the past two decades. This leadership has emerged because of the co-location of ESD's climate modeling community with the scientists leading or participating in all of NASA's satellite missions, the co-location of strong modeling expertise across several Earth science disciplines, and the proximity with NOAA's NCEP. In partnership with NCEP, the Earth Sciences Division led the development of the interagency Joint Center for Satellite Data Assimilation (JCSDA), whose mission is to accelerate the quantitative use of satellite data in weather and climate prediction models for interagency operational and research purposes. This collaborative approach represents a commitment on the part of NASA, NOAA, and DOD to focus on research and operational issues related to improving the forecast of high-impact weather events and extending accurate weather forecasts to day seven and beyond. In addition, GSFC generates research-quality assimilated data sets, including clouds and precipitation, trace gas, aerosol, and climate products, as well as ocean and land surface products, for use by NASA instrument teams, field campaigns, and for research analyses.

An important aspect of NASA's interest in assimilation and weather forecasting is the intimate connection between weather modeling and climate modeling. Increasingly, the international modeling community is calling for "seamless" modeling, where climate models are subject to confrontation with data and are tested in forecast mode, both for weather and for short-term climate predictions, as a metric to assess the reliability of long-term climate predictions. Furthermore, the emerging mandate for air quality forecasting at operational centers has offered the opportunity for GSFC to provide leadership in this area as well.

GISS's activities in climate modeling and prediction predate the United Nations Framework Convention on Climate Change (UNFCC) by at least 20 years. However, NASA's formal role in weather and climate processes can be traced back to the UNFCC, which the United States was the first industrial country to ratify. Its goal is to stabilize atmospheric composition to "prevent dangerous anthropogenic interference with the climate system" and to achieve that in ways that do not disrupt the global economy. This global framework agreement raises fundamental scientific and practical issues that must be addressed if decision makers are to have the quantitative information needed to carry out their treaty responsibilities most effectively. Division scientists have contributed their climate modeling simulations to all the IPCC activities, including the latest IPCC 2007 report. NASA is also one of the core agencies in the multi-agency Climate Change Research Initiative (CCRI) that addresses climate change. Both GISS and GMAO will contribute to the IPCC's Fifth Assessment Report: GISS makes long-term predictions, and GMAO addresses newly introduced decadal predictions.

Climate and weather model development in ESD employs modern programming techniques for high-end computer architectures and involves cooperation across a broad range of science disciplines. Because of the cross-disciplinary nature of model applications, the models used are becoming more complex through inclusion of an increasing number of physical, chemical, and biological processes. One implication of this complexity is the need to adhere to an open standard for building Earth system models; hence, the Earth System Modeling Framework (ESMF) has been adopted in the global models developed in ESD. This strategy for model development takes advantage of the improved modularity of the models, allowing the testing and comparisons of alternative algorithms. While the scientific integration of disparate modeling components can still be a major scientific endeavor, the ESMF acts to minimize the technical impediments of these activities. Under the ESMF, GISS and GMAO now share a common dynamical core; as a result, sharing of future components (such as the ice sheet model mentioned in Chapter 8.2.2) becomes more feasible.

Over the next five years we plan to strengthen and further the collaborations between GISS, GMAO, ACDB, and others in the ESD. This will allow us to benefit from the integrative power of models and assimilation system on the one hand, and from the observational expertise and process science understanding needed for input to these tools on the other.

GSFC and GISS modeling and assimilation efforts aim to address the following:

Scientific Goals

- Develop a system for Integrated Earth System Analysis with state estimates that are consistent across separate components of the Earth system, using observations to provide information on unobserved quantities.
- Enhance prediction of anthropogenic and natural changes in the future Earth environment.
- Identify the merits of existing and the potential of new observations, refining or developing new algorithms for maximizing the benefits of these measurements.

Scientific Questions

- How can weather forecast duration and reliability be improved?
- How can the global observing system be optimized for weather and climate prediction?
- How well can we predict atmospheric composition, and what are the relevant feedbacks for climate and weather prediction?
- How predictable are the dominant modes of climate variability, and what governs their predictability?
- What is driving climate change?
- How does the Earth system respond to changes in climate, and what are the associated feedbacks?
- What are the impacts of climate change?
- What are the links between climate variability and trends and extreme weather, such as hurricanes and severe storms?
- What can humans do to alter the magnitude and direction of climate change?

Heritage

- GSFC has provided leadership in the Agency's modeling and data assimilation capabilities for more than two decades.
- These capabilities have demonstrated the usefulness of AIRS data in improving weather predictions and Microwave Limb Sounder (MLS) data in improving the representation of stratospheric variations. They have also been used to provide meteorological products for NASA instrument team algorithms, such as: MODIS land surface, CERES, MLS, and Troposphere Emission Spectrometer (TES) products.

- Altimeter data have been used in the ocean data assimilation system to help improve seasonal climate predictions.
- GSFC has been a world leader in the development of land surface data assimilation capabilities, especially in the area of soil moisture, where GSFC leads development for the SMAP mission.
- These modeling and data assimilation capabilities are the basis for some of the research-to-operations transition activities with NOAA through the JCSDA, of which ESD is a research partner.
- The Division has participated in assimilation collaborations: The Observing System Research and Predictability Experiment (THORPEX) of the World Weather Research Programme's (WWRP), including a comparison of observation impacts through adjoint tools.
- GSFC has conducted regular seasonal climate forecasts for over a decade, and has contributed the forecasts to the national consensus seasonal climate forecast through NOAA to the International Research Institute for Climate Prediction and to the Asia-Pacific Economic Cooperation (APEC) Climate Center.
- GSFC has provided leadership in the development of a high-resolution atmospheric model for studies of weather-climate interactions that contribute to observing system science studies.
- GSFC is one of the world leaders in reanalysis, particularly of the atmosphere. The Modern-Era Retrospective analysis for Research and Applications (MERRA) has made significant advances on the previous generation of reanalyses, and provides a state-of-the-art meteorological analysis over the satellite era.
- GSFC has demonstrated leadership in the modeling of atmospheric composition, most notably tropospheric and stratospheric chemistry and aerosols, including its coupling with climate.
- GISS's activities in climate modeling and prediction predate the United Nations Framework Convention on Climate Change (UNFCC) by at least 20 years.
- NASA has been a principal source of information about global climate change.
- GSFC, through the activities across the Earth Sciences Division, has been a leading organization in climate research.
- GSFC has been the principal organization to develop the analysis of data, models, and techniques for the assimilation of the data and the validation of the models across the land, ocean, and atmosphere.
- GSFC has been the world leader in providing climate data on changes of ice sheets, sea level, land surface, vegetation, ozone and other gases, aerosols and other climate forcings, and feedbacks and diagnostics.

The activities in this area are directly relevant to each of the NASA Headquarters focus priorities, as well as to many of the missions recommended by the NRC Decadal Survey:

Relation to NASA Priorities and the NRC Decadal Survey

- Modeling and data assimilation play an essential role in each of the six NASA Interdisciplinary Science Focus Areas, with a special role in the areas of Weather, Climate Variability and Change, Water and Energy Cycles, and Atmospheric Composition.
- The NRC Decadal Survey identifies the importance of "models and data assimilation systems that allow effective use of the observations to make useful analyses and forecasts" and bemoans the fact that "the United States has lost leadership to the Europeans in the international arena in an array of pivotal capabilities ranging from medium range weather forecasting to long-term climate forecasting. Without leadership in these and other forecasting capabilities, we lose economic competitiveness."
- GSFC modeling and assimilation efforts are directly relevant to GPM, SMAP, Aquarius, SCLP, NPP, JPSS, ACE, ASCENDS, GEOCAPE, 3D-Winds, and the other missions promoted in the NRC Decadal Survey.
- TRMM contributions to weather forecasting, particularly hurricanes, and other heavy rainfall events.
- Mesoscale model development work.

Strategic hiring within ESD will be needed to address interdisciplinary modeling and the development of a comprehensive Earth system model and assimilation system. Expertise in global atmospheric, ocean, and sea-ice model development is needed to replace scientists who have left the Division in recent years or who can be expected to retire in the coming decade. For GEOS model development, the priority is for scientists to lead developments in cloud microphysics and aerosol-cloud interactions. Because of our focus on the interplay of models and observations, those hires are also required to address the observing system elements of our plans in terms of better use of satellite observations, as well as input to mission design. In particular, a critical position is that of an experienced scientist to lead the development of infrastructure for OSSEs and the linkages and support for emerging mission concepts. For GISS, the highest priority for a civil service hire is for a fresh-out or young scientist with a combination of abilities relating to both instruments and analysis/modeling of atmospheric radiation, including polarization, who is also capable of working with aircraft and satellite experiments, with potential to grow into instrument scientist or project scientist. GISS's second high-priority need is for a person with computer technology expertise, capable of designing and maintaining on-site low-cost multi-processor computer capability, and handling the increasing NASA computer security requirements for GISS, preferably an active productive scientist who understands the computer support services required for effective science research.

8.4.1 Data Assimilation

Data assimilation synthesizes diverse in-situ and satellite data streams into a single product through evaluating and accounting for the uncertainties in the input data sets and in the assimilating model. The initialization of numerical weather prediction models was initially the major driver in developing atmospheric data assimilation techniques, but the approach now provides an essential method of ingesting satellite data into weather and climate models. Ocean assimilation products now initialize ocean weather forecasts and seasonal predictions with coupled models, and improve estimates of ocean climate. Land data assimilation has also matured, stimulated by the availability of satellite-derived soil moisture, ground water, surface temperature, and snow cover measurements. Data assimilation for atmospheric composition has also evolved in recent years, thanks to the wealth of aerosol and chemical observations provided by the EOS platforms.

Assimilation efforts in the Division focus on the following: (1) improvements in NASA satellite data utilization for scientific analyses and initialization of models used for prediction, (2) guidance on observing system development, and (3) production of research-quality assimilated data sets as climate data records. These efforts include the development of meteorological, oceanographic, and land surface analyses, atmospheric constituent assimilation for air quality/pollution forecasts, and assimilation of ocean color measurements. Our assimilation efforts are especially focused on the use of new data types to enhance weather, air quality, and climate prediction. In the next five years, the focus will be on new NASA missions, such as the upcoming GPM, NPP, and JPSS missions, Aquarius, SMAP, and the priority missions identified by the NRC Decadal Survey. In addition, developments will be undertaken for currently available data types that are more difficult to process, such as high-resolution imagery, cloud properties, and data in cloudy and rainy regions.

The atmospheric data assimilation system currently employed in our meteorological analyses is the GEOS-5 Data Assimilation System (DAS), a radiance-based analysis system (the Grid-point Statistical Interpolation [GSI] analysis), that was jointly developed with NCEP, and integrated with the GEOS-5 AGCM. This system is being used in collaborations through the JCSDA to advance the use of hyperspectral data from AIRS, the use of temperature retrievals from the MLS, and ozone retrievals from MLS and OMI, and for development of new capabilities to assimilate MLS radiance data directly. In addition to advancing the use of these new data streams, the developments for AIRS and the Advanced Microwave Sounding Unit (AMSU) help prepare for the Crosstrack Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) on NPP. Like AIRS, CrIS should provide information on ozone and the major greenhouse gases in addition to temperature and moisture soundings needed for weather prediction. The GEOS-5 system is also being used to prepare for the assimilation of ozone data from OMPS on NPP.

Among the most valuable data for process studies and climate analysis are the reanalysis data sets generated by letting a fixed version of a numerical weather prediction/data assimilation system reprocess several decades of observations. The Division has generated a new reanalysis of the satellite era (from 1979 to the present) using GEOS-5. MERRA improves upon the hydrological cycle of previous reanalysis and produces a comprehensive product suite for water and energy budget analysis and for chemistry transport models. As of January 2011 just over half a petabyte of MERRA data had been downloaded from the online access provided by the GES DISC.

MERRA is now proceeding forward in time as a climate data analysis to complement the changing system used to improve weather forecasts. The time series of global monthly-mean precipitation from MERRA and other reanalyses (Figure 8.14) shows that MERRA provides significant improvement over earlier generations of reanalyses in analyzing the water cycle. However, despite the major advances, the latest reanalyses are still significantly impacted by changes in the observing system. Precipitation in MERRA is sensitive to SSM/I and AMSU-A data, while ERA-Interim is sensitive to the assimilation of SSM/I data. Dealing with this sensitivity remains the most pressing challenge for the next generation of reanalyses, and will be a focus of GMAO's research in this area over the next five years.

Another focus of the Division's assimilation efforts is the development of an Observing System Simulation Experiment (OSSE) infrastructure to investigate the potential of new missions. For many missions or new instruments under consideration, OSSEs provide a quantitative evaluation of the potential impact of the data, and a mechanism to examine trade-offs in requirements or design. Such experiments can also prepare for the assimilation of new data so that it achieves its potential impact quickly. The execution of a successful OSSE requires a specialized skill set, and this area is a core competency of the Division. Most of the observations currently used for weather forecasts have been simulated using a simulator tool and a nature run provided by the European Centre for Medium-range Weather Forecasts (ECMWF). Adjoint tools, developed with the assimilation system to evaluate observation impacts on forecast skill, are proving to be a very efficient mechanism for calibrating the synthetic observations generated for the OSSEs. The Division's OSSE capability represents the state of the art in

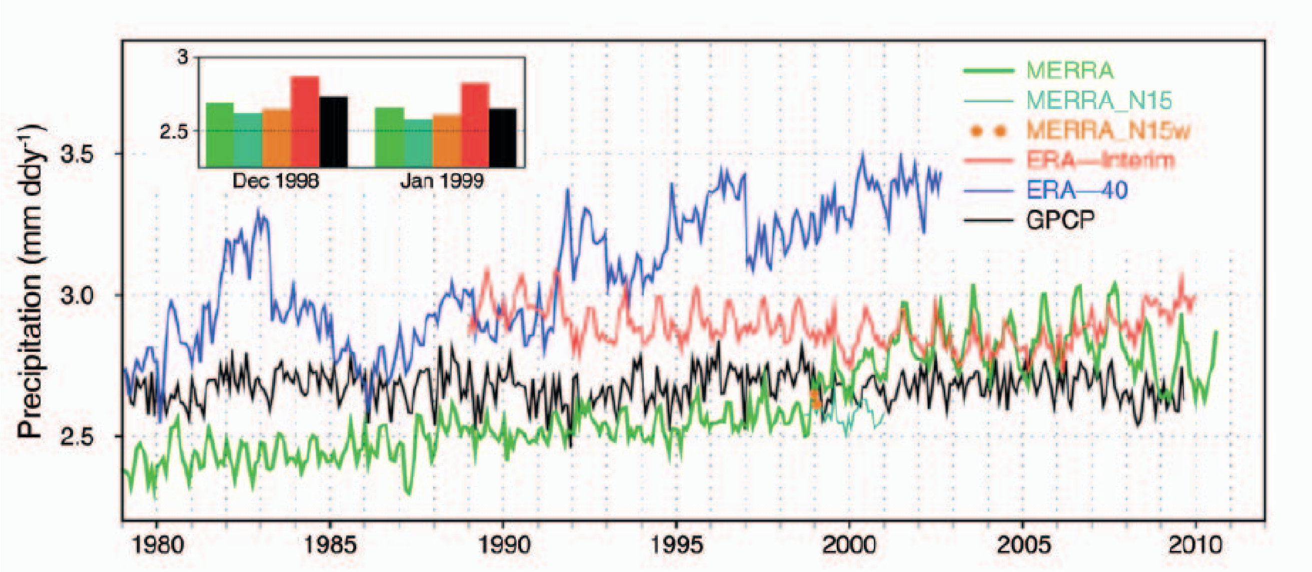


Figure 8.14. Time series of global monthly mean precipitation (mm day^{-1}) for MERRA, ERA-Interim and ERA-40, compared against GPCP. In addition to the time series from the MERRA distribution, two short data withholding experiments are shown. MERRA_N15 is from an experiment withholding all AMSU-A data from NOAA-15; MERRA_N15w withholds only the AMSU-A window channels, 1-3 and 15. For clarity, the inset shows the monthly mean values for December 1998 and January 1999.

the field, and is being used to contribute to wind lidar mission development as well as for other NRC Decadal Survey missions.

Over the next five years, the atmospheric assimilation system will advance to bring in the time dimension more effectively with a hybrid 4-dimensional variational (hybrid 4D-var) approach, merging the best characteristics of 4D-var and ensemble techniques. This is essential for using satellite data more effectively, as these data tend to be distributed throughout the assimilation window, rather than occurring just at the analysis time. A prototype system is currently undergoing testing. In the next five years, this system will mature to replace the operational system used for product generation. We will continue to develop the capability to use rain and cloud-affected radiances to improve atmospheric analyses and forecasts. We will also extend the OSSE capability to missions not focused on weather prediction by focusing on some of the early missions identified by the NRC Decadal Survey, e.g., ACE and ASCENDS.

The ocean and land surface data assimilation capabilities focus on using satellite data to enhance seasonal prediction. The Division has pioneered advanced techniques such as the Ensemble Kalman Filter (EnKF) for the multivariate assimilation needed to take advantage of surface altimetry. The techniques developed for altimetry should also prove effective for ocean color data and the surface salinity data anticipated from Aquarius. Over the next five years, we will focus on making progress with these new data types, especially as they provide information on air-sea fluxes needed for carbon cycle and water cycle studies. We also plan to develop observing system simulation expertise to contribute to future mission design.

The EnKF approach has also been developed to help in dealing with the highly inhomogeneous nature of the errors in land surface models, as well as the multivariate assimilation needed to take advantage of surface soil moisture and snow observations. The land surface assimilation efforts have particularly focused on making effective use of surface soil moisture retrievals from AMSR-E and on the assimilation of terrestrial water storage estimates from GRACE. Preparations are underway for the SMAP mission: After launch, we plan to generate a Level-4 assimilation product for SMAP.

The combination of these activities within the Division places us in a unique position for advancing an Integrated Earth System Analysis (IESA) that is a consistent analysis across the various components of the Earth system. The IESA, another focus of assimilation efforts over the next five years, is being developed through a phased approach of incrementally coupling in different components. For example, an aerosol assimilation effort is tied to meteorological analyses from MERRA; so, too is the latest version of the ocean data assimilation system. The use of MERRA with an historical ocean analysis will provide the initial fields for some of the first tests of decadal climate prediction.

8.4.2 Weather Prediction

The primary responsibility for operational numerical weather prediction (NWP) in the U.S. rests with NOAA. However, NASA plays an important role in assisting NOAA to reach its operational goals. One reason for this is that future improvements in weather forecast skill are most likely to be achieved by improving the use of satellite observations in a data assimilation context. Weather forecasting is largely an initial-value problem; and beyond the three-day range, observations covering the full global domain are required in order to establish sufficiently accurate initial conditions. Scientists from the Division are therefore working closely with their colleagues in operational agencies on testing impacts of new NASA data and on continually improving the use of existing NASA data in operational systems. Our participation in the JCSDA is a major component of these activities. ESD scientists have developed a powerful tool to investigate issues related to the observing system: the GEOS-5 adjoint system. That system has recently been used to document the impact of each component of the current observing system used in operational NWP (Figure 8.15). This information can be used to identify different observations whose use in assimilation could possibly be improved, and it can be used to help make decisions about the future evolution of the observing system.

Currently, the Division is focused on improving the use of EOS data, particularly from AIRS, MODIS, AMSR, and MLS, for weather prediction. One of the challenges is how to make best use of the huge volumes of data in a computationally efficient manner. As we move to higher-resolution models, we are able to reduce the model biases and more effectively use the data. Over the next five years, the Division's two main foci in system development for weather prediction will be the implementation of a hybrid 4D-var, and the development of GEOS-6, the next generation GEOS model that will include a high-resolution, global non-hydrostatic implementation. The transition from the EOS era to the new JPSS and the Earth Sciences NRC Decadal Survey era will also be a major challenge.

The 4D-var data assimilation system is currently in a prototype test phase. Thanks to collaboration between GSFC scientists and colleagues at NOAA's Geophysical Fluid Dynamics Laboratory, the non-hydrostatic model is undergoing testing, tuning, and further development at resolutions down to 3.5 km globally (Figure 8.16). One key near-term development effort is in the computational area, that is, scaling the model to efficient performance on computers using tens of thousands of processors. Of course, at high resolution, the model physics need attention. Another major thrust during the next five years will be the use of a Cloud Resolving Model and the high-resolution data from CALIPSO and CloudSat to help improve the representation of moist processes in the global model. With improved models and a 4D-var assimilation system, we will increasingly bring the models and assimilation system to bear on design of the observing system to support weather prediction applications.

8.4.3 Chemical Constituents - Analysis and Prediction

The assimilation and prediction of atmospheric constituents is a major aspect of our meteorological data assimilation system.

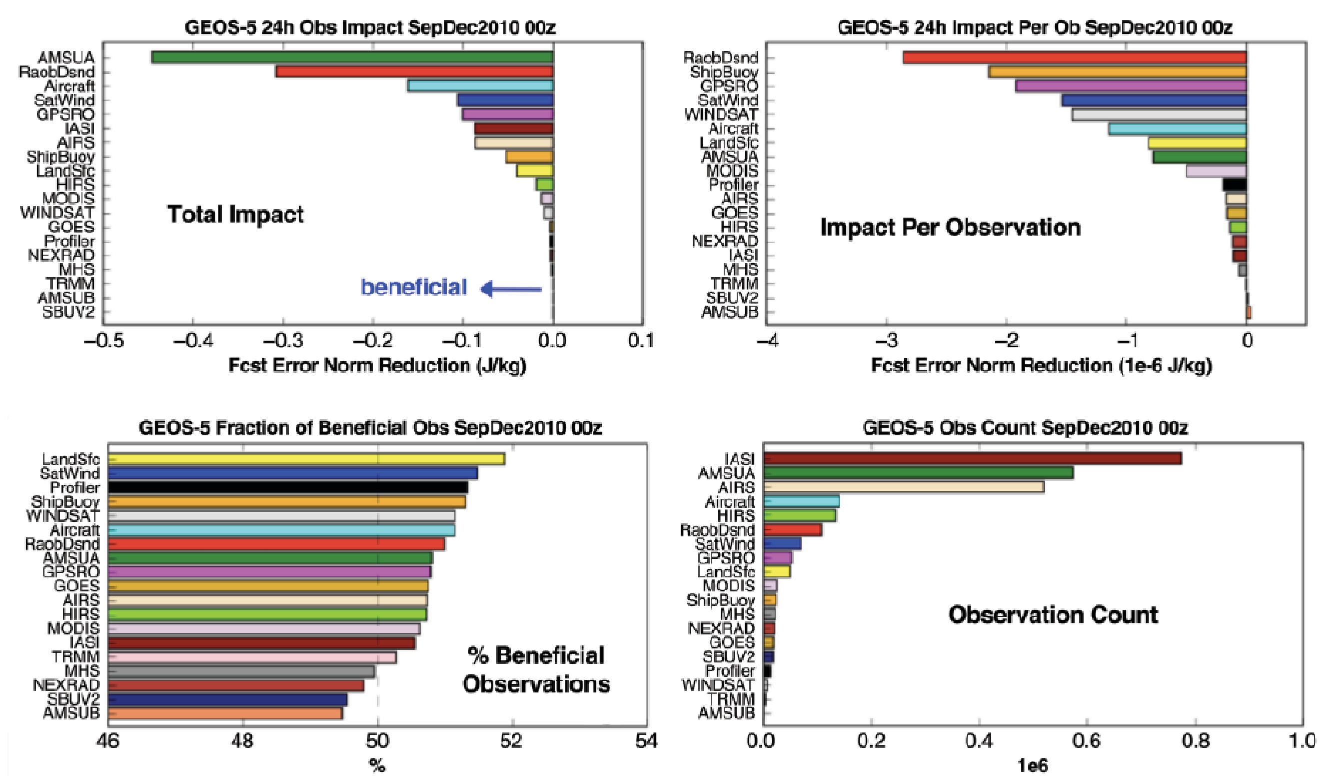


Figure 8.15. Observational impacts in the GEOS-5 data assimilation and forecast system, calculated from 24-hour forecast experiments conducted at 0 UTC from 1 September to 31 December 2010. The impacts are assessed relative to a global energy norm. Negative values in the upper panels indicate that the observations on average improve the forecast.

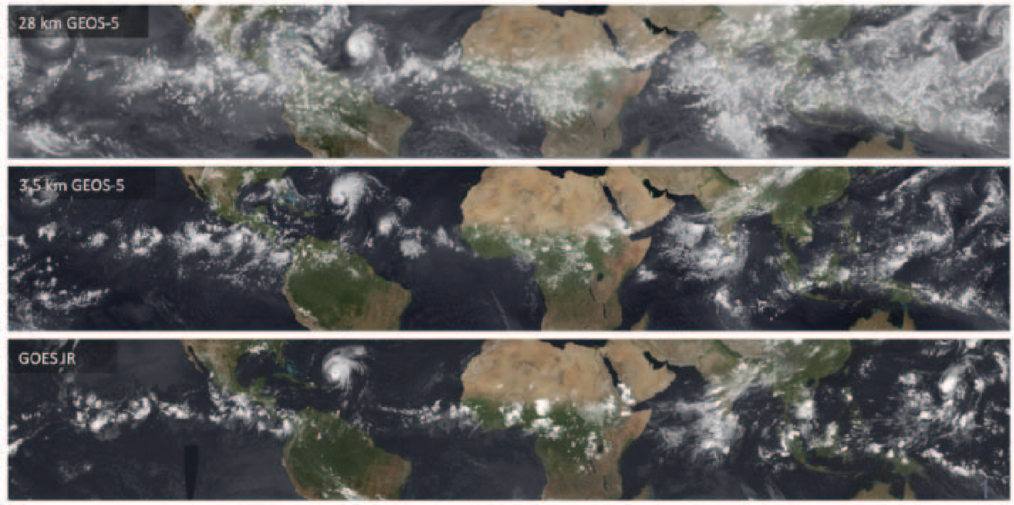


Figure 8.16. Comparison of GEOS-5 forecast for 20 August 2009 using the current production system at about 28-km resolution (upper) and a 3.5-km test system (middle), compared with an IR image from GOES (lower).

In GEOS-5, ozone is assimilated in a multivariate framework along with temperature, moisture, and other meteorological data. Ozone column data from SBUV and OMI are assimilated along with profile data from EOS-MLS. We are currently preparing the GEOS-5 ozone assimilation system for use with OMPS and CrIS data from NPP and JPSS. Future development will incorporate increasingly comprehensive atmospheric chemistry modules that deal with a large number of gases and their interactions with the atmospheric radiation balance. The same models are being used in chemistry-climate mode, to address questions related to past variations of ozone and their impact on the climate, as well as for future climate predictions.

Tropospheric constituent modeling, including aerosols, is motivated by their radiative impacts on atmospheric circulation, and by the important impacts of pollution on human life and ecosystems. Carbon monoxide and several types of aerosols are currently tagged according to their sources, and used to support field campaigns. Support of the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in 2008 and the GloPac mission in 2010 gave considerable exposure to ESD products and capabilities, demonstrating the realism of many aspects of the intercontinental transport predictions in our analyses and forecasts. We are expanding the assimilation capability of the GSI system to include tropospheric constituents in order to monitor and predict pollutant distributions that are related to air quality.

The aerosol data assimilation capability is focused on measurements from the EOS platforms, most notably MODIS, MISR, and OMI. Our strategy consists of using measurements in the visible and UV portions of the spectrum to constrain atmospheric aerosols, and to utilize this information to improve the assimilation of radiances in the thermal IR. The proper handling of aerosol effects is expected to have a positive impact on the assimilation of AIRS and IASI, and improve the analysis of sea surface temperature for NWP. In addition to refining algorithms for assimilating measurements from the EOS platforms, we plan to evolve these algorithms for new JPSS measurements, and to play an active role in the design of new NRC Decadal Survey missions. Active participation in field campaigns will continue to forge a strong and meaningful collaborations with current and future instrument developers. Scientific analysis of the aerosols will include studies of their effect on the atmospheric hydrological cycle, including direct, semi-direct, and indirect effects of aerosols on climate.

Consistent with the nature of most EOS observations of CO, NO_2 and other species that contain geophysical information in the middle troposphere and higher, we will focus our study of tropospheric pollutants on long-range transport. Over the next five years, a major focus will be the carbon cycle. We will develop the capability to assimilate a range of observations of CO_2 and other relevant parameters, and develop inversion techniques to infer surface sources and sinks from upcoming atmospheric observations. One of the goals will be the estimation from numerous types of measurements of spatial distributions of carbon fluxes between land and oceans and the overlying atmosphere, as well as the estimation of biomass emissions from satellites. This will contribute to NASA's CMS activities as well as to the development and uncertainty assessment of model components for Earth system prediction activities.

The retrospective analyses of atmospheric constituents have been important for studies of the variability in aerosol and trace gas distributions. The Division has built upon the meteorological analysis and software infrastructure of the GEOS-5 Data Assimilation System used to produce consistent distributions of aerosols and trace gases as a phased approach to developing an IESA. Over the next five years, this system will be used for a reanalysis of the EOS era, since the EOS observations can be used for evaluation of the model-generated products.

8.4.4 Subseasonal-to-Decadal Climate Variability and Prediction

One of the key questions that NASA's research seeks to answer is the extent to which transient climate variations can be understood and predicted. It is now clear that SST changes have profound impacts on seasonal-to-interannual variations and also on long-term hydroclimate variability in many regions throughout the world. There is also emerging evidence that in some regions land feedbacks may play an important role. For example, Division scientists investigating why droughts seem to be less predictable than wet conditions over the U.S. Great Plains found that the changes in predictability are primarily driven by changes in the strength of the land-atmosphere coupling. There are, however, a number of uncertainties about the physical processes that link regional climate to remote SST changes, the strength and nature of the land impacts, and the predictability of regional hydroclimate variations on seasonal to decadal time scales. The Division's research addresses these issues.

The Division has developed advanced assimilation techniques to improve seasonal prediction skill by using the information in satellite altimetry. We have also shown that soil moisture data can significantly influence predictions of summertime precipitation over some continental regions. Our seasonal predictions are regularly included in the consensus forecasts at NCEP and at the International Research Institute for Climate Prediction. Collaborations with NOAA, through its Climate Test Bed, are emerging. Diagnoses of real-time drought information and seasonal drought forecasts from our ongoing seasonal climate forecasts are contributed to the U.S. Drought Monitor and the U.S. Seasonal Drought Outlook, prepared by the National Weather Service Climate Prediction Center, the U.S. Department of Agriculture, and the National Drought Mitigation Center.

Division scientists have led the Global Land-Atmosphere Coupling Experiment (GLACE), a successful international project aimed at quantifying across a broad selection of global climate models the degree to which simulated precipitation responds to soil moisture information. We are now helping to lead the GEWEX/Climate Variability and Predictability project (CLIVAR) GLACE-2. With a wide variety of models, this ambitious project examines the degree to which monthly precipitation and temperature forecasts can be improved through proper initialization of soil moisture. For the first time, a global consensus will emerge regarding the value of land initialization for forecasts, perhaps motivating national forecast centers to make full use of land moisture initialization in their operations.

On decadal timescales, we focus on understanding the sources and predictability limits of long-term droughts, assessing the nature and predictability of Pacific Decadal Oscillation (PDO)-like SST variations and of Atlantic Multi-decadal Oscillation-like SST changes, with a focus on the role of the thermohaline circulation (the Meridional Overturning Circulation). We are undertaking simulations and prediction experiments to contribute to the fifth assessment report of the IPCC. We also plan to undertake simulations and predictions using the GEOS Chemistry-Climate Model (GEOS CCM). We will use the GEOS-5 model and the GEOS CCM in simulations to contribute to the collaborative Coupled Model Intercomparison Experiment.

Given that GEOS-5 has been developed as both a weather and climate model, we are using high-resolution climate simulations to investigate the impacts of climate on weather extremes such as tropical storms. The GEOS-5 model and assimilation systems have also been used for climate attribution studies, identifying (for example) the role of sea surface temperature anomalies in the Atlantic *versus* the Pacific in the February 2010 Eastern U.S. snow storms (Figure 8.17). Similarly, the large-scale circulation anomalies that led to both the Pakistan floods and the Siberian fires in 2010 have also been investigated. Such attribution studies illustrate the power of models to contribute to understanding environmental variations around the globe. These sorts of studies will continue over the next five years as we try to understand the anthropogenically-forced *versus* natural variability in climate and weather extremes.

Over the next five years, our modeling and assimilation efforts will continue to explore the impact of coupled prediction strategies and observations on prediction skill at subseasonal to decadal timescales. Major foci will include identifying the roles that specific observations play in extending prediction skill, and developing effective initialization strategies. Reducing model biases that inhibit skillful forecasts will require, among other things, model developments that improve the boundary layer processes at the air-sea interface. Our strategy for truly coupled atmosphere-ocean assimilation for the IESA also includes updating the boundary layer models in both the atmosphere and the ocean. The next-generation model, GEOS-6, will include aerosol-cloud interactions to model aerosol indirect effects on climate. For this, we have begun developments in cloud microphysics, and plan to incorporate a more-advanced aerosol model. These developments will be the primary thrust in GEOS model development over the next five years.

8.4.5 Climate Change Modeling and Analysis

Climate change has become the central research topic for Earth sciences in the 21st century. Human-driven forcings of the global climate system are already large enough to dominate over natural forcings on decadal and longer time scales. It is therefore imperative, for the sake of the public and the planet, that a better understanding be developed of what is driving climate change, what the impacts of climate change will be, and what humans can do to alter the magnitude and direction of climate change.

NASA has been a principal source of information about global climate change, including changing climate forcings such as total and spectral solar irradiance (see Figure 8.18), stratospheric ozone, volcanic aerosols, as well as human-made aerosols and gases. NASA also provides key observational data about changing climate responses, including masses of the ice sheets and sea level, accelerating dynamics of ice streams, decreasing sea ice cover in the Arctic, poleward movement of forest cover, and other relevant measurements of global change (e.g., Figures 8.17, 8.18, and 8.19).

The long solar cycle minimum in 2008-2009 (Figure 8.18) is expected to be followed by a low solar cycle maximum, much lower than recent solar cycle maxima, and perhaps similar to the low cycles during the Gleissburg Minimum in the early 1900s, or even, perhaps, to the Dalton Minimum in the early 1800s. If the next cycle, Cycle 24, is indeed weak, then the next few years will provide a natural laboratory to study how climate responses change or are different during a period of low solar activity. Some of the climate responses, for the ocean mixed layer and near-surface atmosphere, have decadal or multi-decadal time constants, so a long-lasting low solar cycle can test

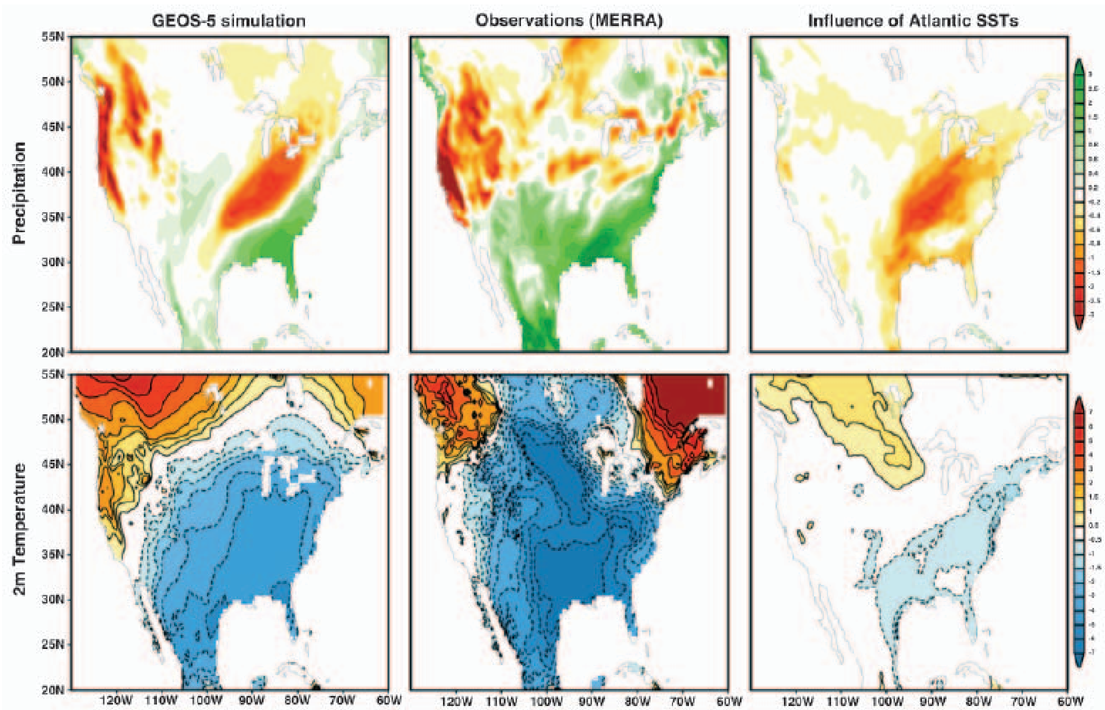
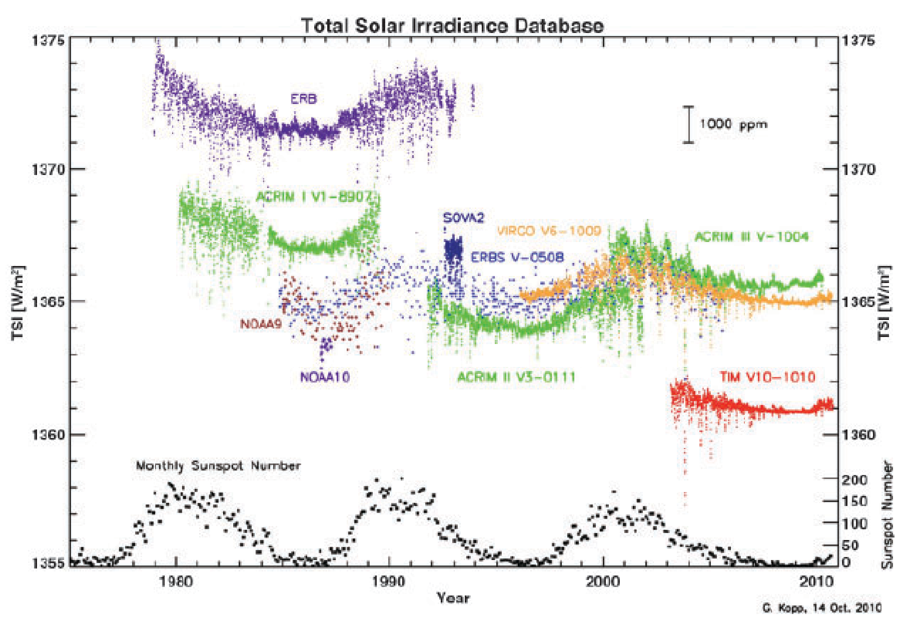


Figure 8.17. The ensemble mean difference of 0.5° GEOS-5 simulations for the 2010 winter (El Niño conditions in the Pacific with a negative North Atlantic Oscillation [NAO]), compared with the 2000 winter (La Niña conditions with a positive NAO) in a study for attribution of the February 2010 snowstorms. Results indicated that the enhanced storminess and increased precipitation was largely due to El Niño. The NAO (in response to Atlantic surface temperatures) produced colder temperatures, i.e., snow instead of rain.

Figure 8.18. The space-borne Total Solar Irradiance (TSI) database. Space-borne measurements of the TSI show ~0.1 percent variations with solar activity on 11-year and shorter time scales. Offsets between instruments are the results of calibration differences. Recent comparisons with the cryogenic radiometer as LASP show prospects of greatly reducing these differences. Glory will carry the first Total Irradiance Monitor (TIM) that will have full traceability to the cryogenic radiometer standard, the TSI Radiometer Facility (TRF) at the University of Colorado.



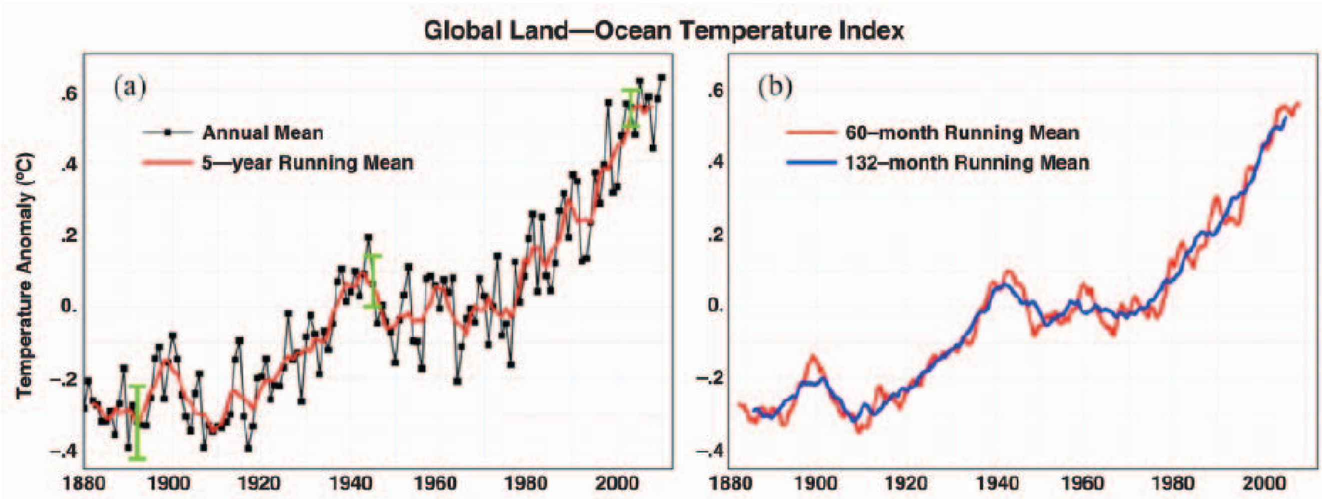


Figure 8.19. 2010 was a statistical tie with 2005 as the warmest year in the GISS record. The warming rate averaged over solar and Southern Oscillation cycles has been nearly constant for three decades.

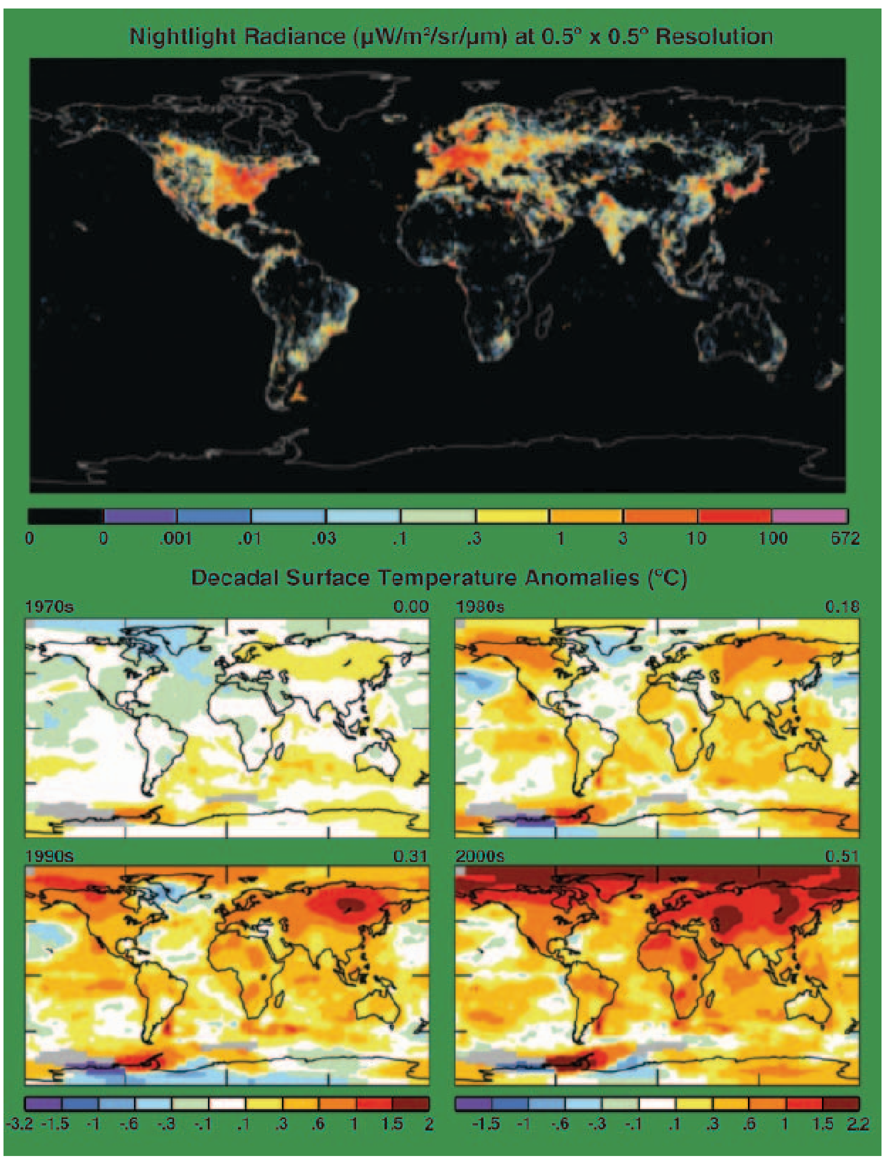


Figure 8.20. Upper: GISS uses satellite-observed night lights to identify stations located in "pitch black" locations. Lower: The temperature anomalies over the last four decades.

and challenge our understanding and models of climate change. CERES and CLARREO, in combination with the Solar Radiation and Climate Experiment (SORCE), and successors Glory and Total Solar Irradiance Sensor (TSIS), will provide new information on Earth's radiative balance that drives climate change. GSFC and the University of Colorado Laboratory for Atmospheric and Space Physics (LASP), who cooperate in the solar missions Solar Dynamics Observatory (SDO), SORCE, and the successor TSIS (within JPSS), have recently formalized their collaboration in this area in a "Sun-Climate Research Center" that will involve four Sun-Climate fellows from each center – heliophysicists and Earth scientists working together on the interdisciplinary problems related to Earth's responses to solar variability.

GSFC has been a leader in interpreting the causes of climate change and in projecting the possible impacts of alternative scenarios for continued human emissions. This has been the result of our development and validation of climate models and data assimilation techniques. Over the last year, significant accomplishments at GISS included getting Glory ready for its February 2011 launch, and getting the GISS global climate model ready for simulations for the next IPCC report.

Long-Term Climate Change

Climate simulations must cover time scales ranging from the industrial era to paleoclimate. The industrial era is of immediate importance due to the need to address policy issues relating to mitigation of anthropogenic climate change effects, and for planning for adaptation to future climate change. Paleoclimate research is of equal importance because of the scientific insights and understandings provided by climate model simulations across major past changes in Earth's climate. These climate simulations need to include high spatial resolutions, so that they can contribute to climate impact studies and to climate process studies on regional scales. Accurate climate simulations require that the model include the full Earth system, including full atmospheric and oceanic circulations and coupling, as well as chemical, cloud and aerosol, and Earth surface processes that affect Earth's radiation balance. Our modeling includes all climate forcings and feedback processes, as well as climate diagnostics that are derived from satellite observations, and analyzed with the help of appropriate modeling (e.g., Figure 8.21). Precise measurements of ice sheet mass balance and topography provide one example of important diagnostics. In combination with modeling and field studies, these measurements allow investigation of possible nonlinear responses of ice sheets to growing anthropogenic climate forcing.

8.5 Earth Observing System (EOS) Project Science Office

The Earth Observing System (EOS) Project Science Office (PSO) at GSFC, an important partner in the implementation of the EOS program, continues to carry out important functions related to EOS and other NASA ESD missions. Current PSO

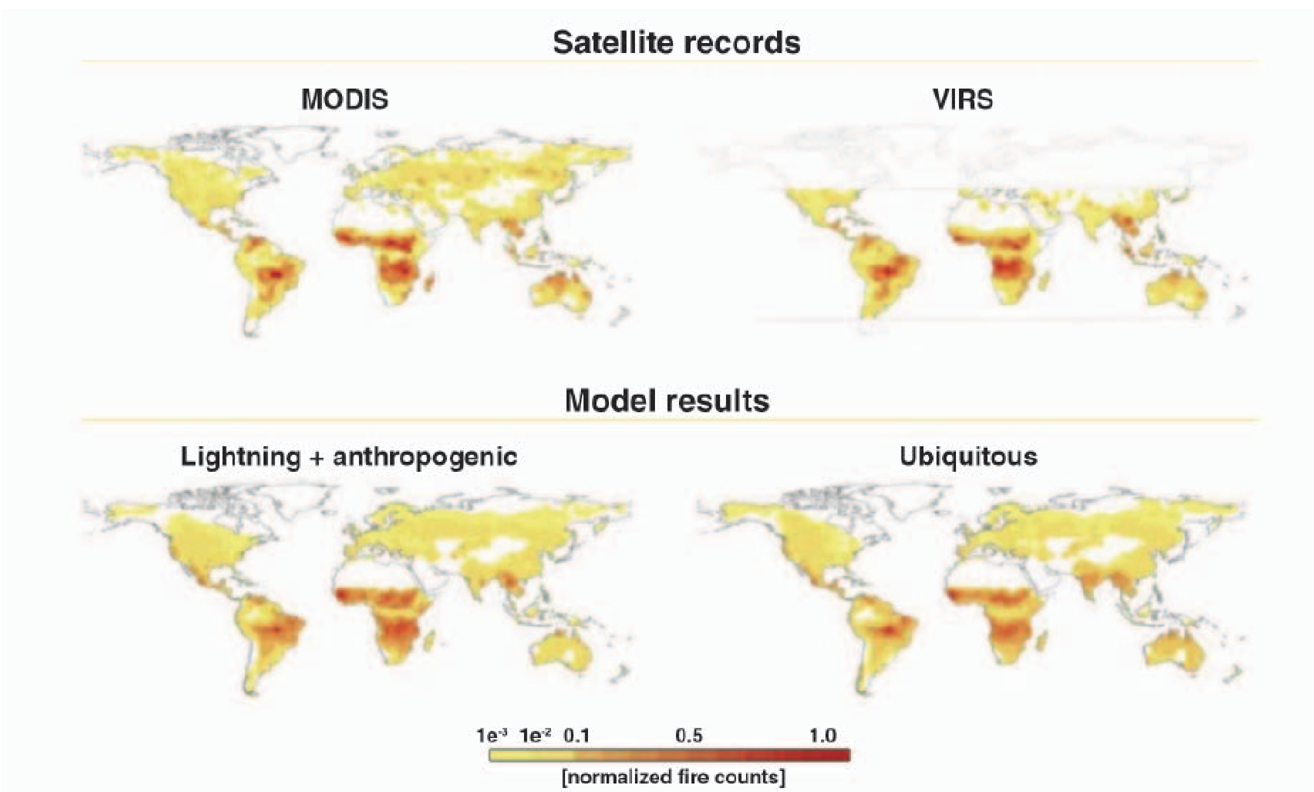


Figure 8.21. The 2001–2005 annual mean fires recorded by MODIS and VIRS, and the GISS model parameterization, with ubiquitous and lightning and anthropogenic ignition sources.

support, via direct NASA Headquarters funding (primarily from the ESD Research Office), is summarized below.

Mission Project and Deputy Project Scientists

Project Scientists and their deputies perform a critical role for the Center, for NASA ESD, and for the greater science community. To help enable this important effort, labor and procurement support is provided for existing EOS mission project scientists/deputies (Terra, Aqua, Aura, SORCE, ICESat, Landsat) and will be available for future Glory, NPP, and LDCM mission project scientists after launch. This support includes the EOS Validation and Calibration Scientist positions.[1]

Historically, the EOS science organization was designed to help unify and focus science efforts across a broad range of programmatic goals for the multiple EOS missions. This was achieved via a close working relationship between the EOS program scientist and the EOS PSO, both working directly with the EOS Program Office. In a like manner, we propose that an expanded EOS Project Science Office, working closely with the NASA Headquarters' Earth Science Division and the GSFC Earth Science Projects Office (Code 420), and incorporating other NASA center expertise, will be able to provide the important organizational function of assisting in cross-mission science efforts for NRC Decadal Survey and Climate Continuity Missions. With these partner organizations, we will explore development of an expanded and suitably renamed project science office (e.g., Earth Observations Project Science Office), within the ESD, headed by a project scientist and assisted by a deputy.

[1] A complete list of project scientists for these missions is given in Appendix C.

Calibration/Validation

A broad range of laboratory calibration and validation instrument capabilities are supported, including the following:

- Calibration: Collectively, PSO-supported laboratories maintain radiance sources and spectral measurement equipment covering the range from the UV through the thermal infrared, reflectometry measurement systems, and thermal and/or vacuum chambers.

  - Three EOS-supported GSFC facilities are the Radiance Calibration Laboratory (lead: Jim Butler), Diffuser Calibration Laboratory (lead: Jim Butler), and the Calibration Development Laboratory (lead: Scott Janz) (see Figure 8.22). In addition, a radiometric and spectral lab is supported at the NASA Ames Research Center's Airborne Sensor Facility. These labs have maintained strong ties to the Optical Technology Division of the U.S. National Institute of Standards and Technology (NIST) since the mid-1990s, during EOS development. Over the years, these facilities have provided their services and expertise to a number of instruments, instrument

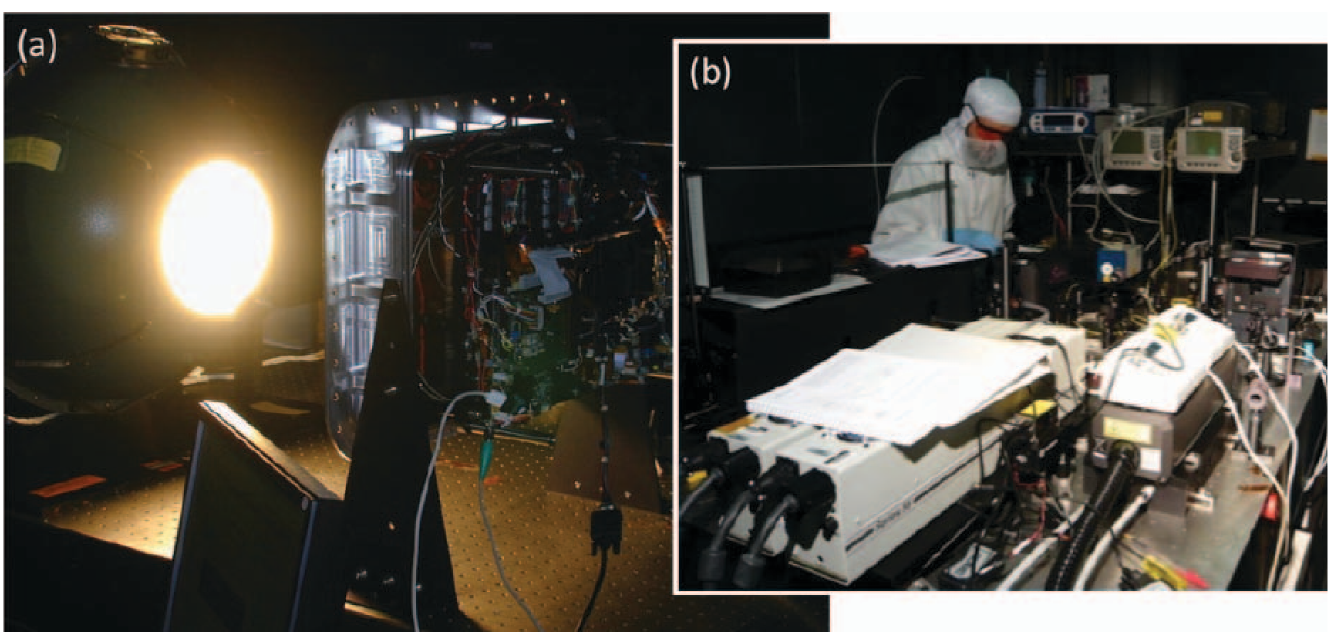


Figure 8.22. (a) Radiometric calibration of the Airborne Compact Atmospheric Mapper (ACAM) in the Calibration Development Laboratory. (b) The continuous-wave fixed- and tunable-wavelength lasers located in the Radiometric Calibration Laboratory. These lasers are used in end-to-end wavelength and radiometric calibrations of ground-based, airborne, and satellite instrument systems.

teams, projects, agencies, and missions, including those of international partners.

- Validation: The EOS PSO supports ground-based networks and aircraft facility instruments.

  - Two networks are supported: The AERONET program is a federation of ground-based remote sensing a aerosol measurement networks established by NASA and PHOTONS (University of Lille, the Centre National d'Etudes Spatiales [CNES], and the French National Center of Scientific Research [CNRS]-National Institute for Earth Sciences and Astronomy [INSU]), with collaborators from national agencies, institutes, universities, individual scientists, and partners. The program provides a long-term, continuous, and readily accessible public domain database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other datasets. The other network, the NASA Micro-pulse Lidar Network (MPLNET), is a federated network of micro-pulse lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods. Most MPLNET sites are co-located with sites in AERONET.

  - Two airborne imagers are supported: The MODIS Airborne Simulator (MAS) is a scanning grating spectrometer imager, with 50 spectral channels, 50-meter nadir spatial resolution, visible through the 14µm spectral coverage from visible wavelengths through 14 µm, used for cloud, aerosol, fire detection, and surface features. It is flown on the NASA high-altitude ER-2 aircraft. The MODIS-ASTER Simulator (MASTER) is similar to MAS, but with changes in the spectral band positions in order to better simulate both ASTER and MODIS. It has flown on the WB-57, B-200, and ER-2aircraft. Both sensors have been used for application support, i.e., natural hazard and disaster response. An improved sensor system, referred to as enhanced-MAS (eMAS), is in development.

Public Outreach

A variety of outreach activities are pursued under EOS PSO support. The core activities are given below. Further details on many of these efforts are given in Appendix B.2.

- Provifing printed materials: posters, brochures, graphic support, activity booklets, etc., related to specific missions, mission constellations, and science themes.
- Conference and exhibit support: This includes developing and staffing exhibits at professional society meetings, national and international science organizations, and public events. In addition to ESD-related efforts, the relevant task also works with directed funding from other science divisions at NASA Headquarters. Over 30 exhibits were supported in 2010, including 7 international events.
- Publishing the *Earth Observer* newsletter: This bimonthly overview of NASA Earth science and outreach activities, science team meetings, historical articles, etc., goes out to about 6000 national and international subscribers. The printed version is now supplemented by a color electronic version. The latest issue is available for download at (http://eospso.gsfc.nasa.gov).
- Publishing the Earth Observatory web site: The award-winning site's mission is to share with the public the images, stories, and discoveries about climate and the environment that emerge from NASA research, including its satellite missions, in-the-field research, and climate models (http://earthobservatory.nasa.gov). The same team works with two closely related sites: NASA Earth Observations (NEO) and Visible Earth (VE).

8.6 Managing and Analyzing Data

The ESD plays a leading role in the development and evolution of science data systems to generate and manage Earth system science data and information. ESD institutional strengths in science data system development and operation are listed in Table 8.1. The ESD does cutting-edge research in the design and evolution of data systems used to support diverse science measurements as shown in Tables 8.2 – 8.6, below. Thus, rather than the "one size fits all" model of the original Earth Observing System Data and Information System (EOSDIS), ESD provides data system capabilities that have evolved to address science discipline-specific (e.g., ocean, land, atmosphere and precipitation) requirements for data products and related information and services.

Discipline-oriented data systems have been shown to reduce overall maintenance and operational costs compared to a consolidated system such as EOSDIS. These systems (and related expertise) have been reused for multiple instruments, thereby reducing new mission startup cost, schedule, and risk.

Our data system capabilities include science algorithm development and integration, data product generation/reprocessing, product analysis in support of product validation, archive management, data search and access, data mining, data

Table 8.1. ESD institutional strengths in science data system development and operation

Strengths	Skill Areas or Capabilities
Close working relationship with science teams and community	Algorithm Development/Integration, Data Calibration/Validation, Research Products, Discipline-oriented Services
Lifecycle experience and authority to control cost, risk, requirements tradeoffs	Project Management, System Design, Development/Reuse, Operations, Configuration Management, Sustaining Engineering
Science insight to develop/refine science data products and services	Data Format, Data Mining, Multi-Mission Products, Visualization/Analysis, Applications, NRT products, Provenance, Quality Assessment
Operationally proven data system components serving multiple missions	Data Acquisition, Processing, Archive, Search and Product Distribution
Pursuit of emerging technology and standards	Scalable H/W, Data Interoperability, Services Interoperability, VME, Cloud Computing

analysis and visualization and data distribution. We are active in the development and application of advanced capabilities that promote the discovery and maximize the availability and usefulness of science products. There is an extensive outreach effort that takes place through publications and presentations at science conferences and workshops which, in turn, increase awareness and utilization of available products and services.

In addition to managing, producing, and distributing data sets, ESD performs original applied research in computer science areas, such as artificial intelligence, data compression, computer graphics, and image processing. These provide both short-term and long-term benefits to NASA data and information systems. The ESD develops advanced computer data acquisition systems to meet the research needs of oceans, atmospheres, weather, land, climate, and hydrology researchers, develops advanced data storage, data compression, analysis techniques, and distributed system architecture technologies.

The ESD is actively pursuing a number of initiatives to promote greater efficiency in our instrumentation development and data stewardship activities. These may include, utilizing commodity hardware to improve system reliability and performance while reducing cost; leveraging common building blocks via collaboration in computing platforms, reusable processing and archive frameworks and user applications/interfaces; adopting common interfaces and protocols for interchange data management systems/tools; sharing in-house experience and practices for design/development/operations and new technology; and examining the benefits/limits of virtualization, cloud computing, and federated data services with respect to science data systems.

8.6.1 Data Management Focus Areas

The ESD data management capabilities at GSFC are roughly categorized into five focus areas. Four of the focus areas group the capabilities according to type of data, i.e., Mission Data Products, Long-Term Data Records, Model Products and Applications, and Near-Real-Time Products. The fifth focus area, Data Discovery, lists systems used for discovery and access to data and information spanning multiple science disciplines and data types. The selection criterion is to include long-lived data systems or products that have an operational emphasis, i.e., for which the principal purpose is to carry out the operational support of Earth science data. In this context, an operational data system supports science data and information products from Earth and space science missions, instruments, and models, and is designed to meet requirements for schedule, timeliness, functionality, reliability, and quality. The various aspects of support include both data and user-support activities. The data activities include acquisition, processing/modeling, quality assessment, validation, archive, access, discovery, and distribution. The user-support activities include mission operations, algorithm and systems development, integration, and testing.

Mission Data Products

The production and reprocessing of mission data products starts with minimally processed instrument data and progressively generates more advanced science products that are easily usable by the science community. Operations on the data include instrument error correction, flat fielding, calibration, geo-location, re-sampling, coordinate transformation and applying science algorithms to transform from instrument counts to physical parameters (e.g., sea surface temperature, radiant flux, land cover usage, etc). Product generation typically incorporates high-volume throughput, one-to-two-day turnaround time with a few near-real-time turnaround times, high operational reliability, and parallel development and operational environments to allow science algorithm upgrades while not disrupting ongoing operations. The reprocessing rate is much higher than the forward processing rate to enable multi-year mission to be reprocessed in only a few months. For example, the ODPS reprocessing rates are > 5,000x for SeaWiFS and >150x for MODIS. ESD-supported mission data products are listed in Table 8.2.

Mission data product archive and distribution typically involves large-volume and long-lived archives of remote sensing and in-situ scientific data. The supported functions include long-term stewardship of data and creation of value-added products for the science community, such as the MODIS phenology metrics

Table 8.2. List of ESD supported mission data products. Web links to the data sources and/or access points are shown in blue.

Mission Data Product Capabilities	Missions Supported
Atmospheric Composition Processing System (ACPS): http://macuv.gsfc.nasa.gov/	Aura (OMI) processing, NPP (OMPS) product assessment/validation [future mission]
AVDC (Aura Validation Data Center): http://avdc.gsfc.nasa.gov/	Aura instrument validation
GES DISC - multi-mission archive and distribution; AIRS processing: http://daac.gsfc.nasa.gov/	Aura (HIRDLS, MLS, OMI, SORCE), Aqua (AIRS) TOVS; OMI, MLS, CloudSat, CALIPSO, MODIS, POLDER, GEOS-5 (fp), MERRA, GLDAS, TRMM (LIS, TMI, VIRS)
Glory Processing System [future mission] - see Glory science page: http://glory.giss.nasa.gov/	Glory (APS)
GLAS Products from ICESat: http://nsidc.org/data/icesat/data.html	ICESat (GLAS)
LAADS (MODIS Level 1 and Atmospheres Archive and Distribution System): http://ladsweb.nascom.nasa.gov/	Aqua & Terra (MODIS)
Land PEATE (Product Evaluation and Algorithm Test Element) [future mission], access to site limited science team members: http://landweb.nascom.nasa.gov/cgi-bin/NPP/NPPlogin.cgi	NPP-VIIRS [future mission]
MPLNET (Micro Pulse Radar Network: http://mplnet.gsfc.nasa.gov/	AERONET, CALIPSO, ICESat (GLAS)
OCDSPS (Ocean Color/SST Data Processing System): http://seawifs.gsfc.nasa.gov/	MODIS (Ocean Color, SST), SeaWiFS. CZCS, MOS, OCTS, Aquarius [future mission]
PPS (Precipitation Processing System) Multi-Mission: http://pps.gsfc.nasa.gov/	TRMM (LIS, TMI, VIRS), GPM [future mission]

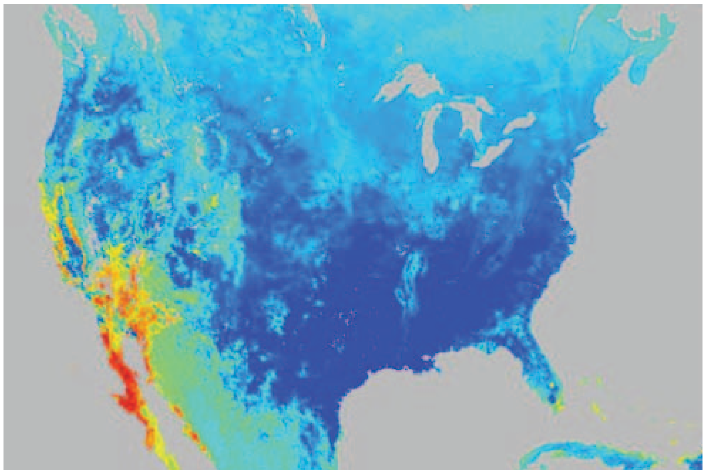


Figure 8.23. Vegetation green-up start day-of-year phenology metric. This is a value-added product derived from the 500-m Normalized Difference Vegetation Index (NDVI) using data from Terra MODIS, and was produced to support principal investigators modeling North American Carbon.

products shown in Figure 8.23, and highly interactive services, including web-based tools for search, access, distribution, subsetting, product tracking, and community problem resolution. An example data browse/search tool is shown in Figure 8.24. Examples of new missions and field experiments assigned to be supported by GES DISC include: Glory, seven atmospheric science MEaSUREs projects, ACOS, GPM, and OCO-2. Figure 8.25 shows the multi-mission browse/search tool to view or search ocean data via multiple search criteria, including mission, location, and timeframe.

The ESD mission support data systems are heavily used, as demonstrated by the following metrics for 2010:

- MODAPS/LAADS: archive volume 1,955 TB, distributed 1,781 TB (120 million files)
- GES DISC: archive volume of 383 TB, distributed 73.6 TB (~11.3 million files)
- ODPS: archive volume of 1,500 TB, ~15 million files
- PPS: archive volume of 275 TB, data distribution of 360 TB (standard products) and 180 TB (near real-time).

The daily volume of MODIS standard science products distributed to the public, the MODIS Science Team, and EOS Distributed Active Archive Centers grew to nearly 8 TB, as shown in Figure 8.25.

A key aspect of all satellite data products is determination of a product's accuracy under various global conditions over the course of the mission. ESD has a strong history of coordinating and leading international land product validation activities through EOS MODIS and the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) Land Product Validation (LPV) sub-group (http://lpvs.gsfc.nasa.gov/). Over the last decade, significant progress has been made toward validation of several land products, including fraction of land cover, active fires, Leaf Area Index (LAI), and albedo products. Similar efforts are now required for global products, including fraction of absorbed photosynthetically active radiation (¦APAR), burned area, soil moisture, vegetation phenology, snow cover, and land surface temperature. Key to direct validation of a satellite-derived product is the collection of field measurements under a range of environmental conditions and coincident with airborne and satellite measurements. There are currently 34 EOS validation Core Sites (Figure 8.26) that continue to provide the EOS science community with ground, aircraft, and satellite data for science and validation investigations. In addition to these core sites, ground measurement and instrumented networks such as LTER sites and FLUXNET also provide increased global sampling for product validation. Research is being conducted to assess the spatial and temporal "representativeness" of tower network sites to improve ground-to-satellite scaling procedures.

The scientist who chairs the Land Product Validation sub-group of the CEOS Working Group on Calibration and Validation (WGCV) is a contractor within the ESD. As chair of the LPV, she has actively expanded its activities to include planning validation activities with ESA, and is addressing best practices for validation and product intercomparison. Hiring this early-career scientist will ensure that key validation activities that will be needed to assess the accuracy of future moderate-resolution Earth-observing instruments will move forward.

Long-Term Data Records

Earth- and space-observing satellites have been flown by NASA since the mid-1970s. After launch, scientists continue to develop algorithms and explore techniques for improving the quality of the data obtained from the sensors. This effort often extends well beyond our own satellites and sensors to those launched by other organizations – both domestic and international. Over time, the collection and reprocessing of the data from these early sensors and the process of combining data from more-recent sensors with older data has led to the development of what is called "long-term data records." Examples of long-term data records are shown in Table 8.3. The supported

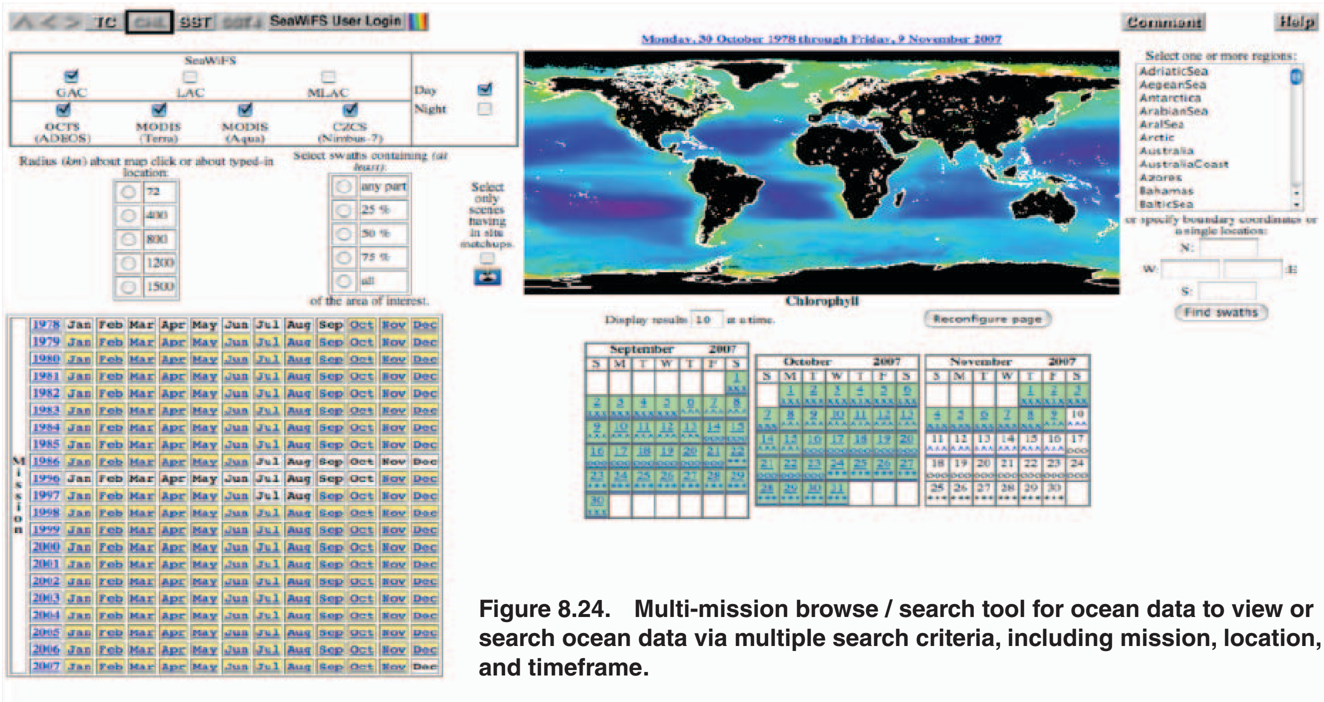


Figure 8.24. Multi-mission browse / search tool for ocean data to view or search ocean data via multiple search criteria, including mission, location, and timeframe.

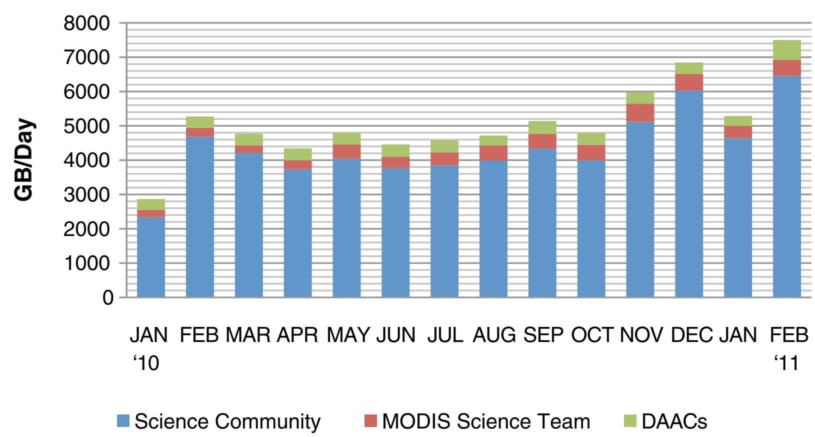


Figure 8.25. Average daily volume of MODIS science products distributed to the public, MODIS principal investigators, and EOS Distributed Active Archive Centers from January 2010 through February 2011.

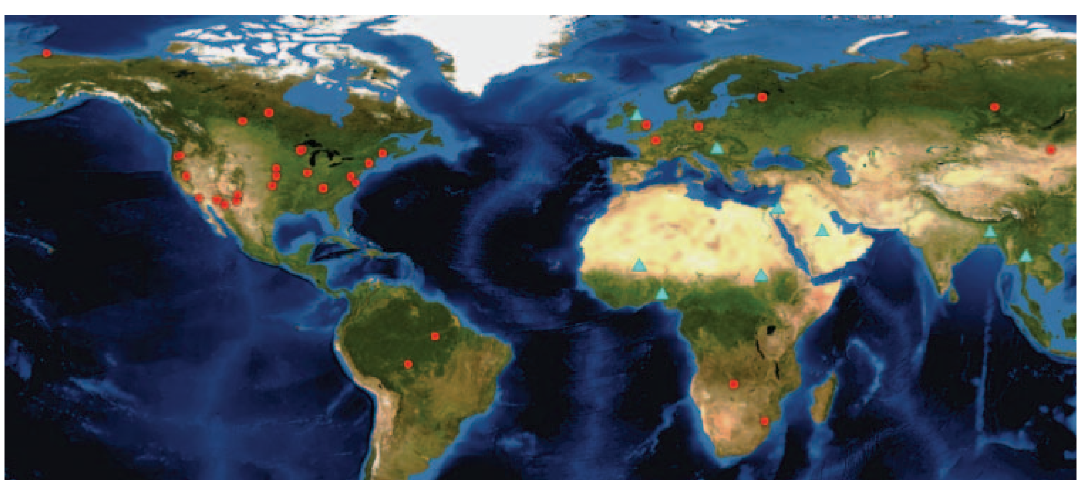


Figure 8.26. Location of 34 existing EOS land validation Core Sites are shown with red circles. Proposed EOS Core Sites (15) are shown by the light blue triangles.

functions include data acquisition, data integration, processing/reprocessing, science algorithm development, data analysis and validation, archive, and data access and distribution.

The Long-Term Data Record (LTDR) project was undertaken to produces a time series of land products from AVHRR and MODIS, from 1981 to present. Data sources for the time series are shown in Figure 8.27. As illustrated in Figures 8.28, the AVHRR solar channel preflight calibration is insufficiently accurate, and the calibration for most of the AVHRR instruments degrades with time. As a result, these instruments need to be calibrated vicariously. Figure 8.29 illustrates an AVHRR scene from NOAA 16 before and after atmospheric correction; Figure 8.30 is a global composite of the land surface reflectance product from one day of the AVHRR time series. The time series from AVHRR through MODIS provides a data record spanning three decades for studying land cover and ecosystem change. Data products from the VIIRS instruments on NPP and JPSS will extend this land data record by another 20 years.

Accurately calibrated and geolocated data sets from Earth-observing instruments which span decades will enable

Table 8.3. Examples of ESD-supported long-term data records grouped by science discipline. Web links to sources and/or access points are shown in blue.

Science Area	Long-Term Data Records	Data Sources
Atmospheric Composition	Satellite ozone data sets – total ozone and ozone profile data set since 1970, surface UVB and aerosol absorption data since 1978. (http://jwocky.gsfc.nasa.gov)	SBUV, TOMS, OMI
	Global Aerosol Climatology Project (GACP) data set since 1981. (http://gacp.giss.nasa.gov)	NOAA/AVHRR
	Aerosol products for land and ocean since 2000. (http://ladsweb.nascom.nasa.gov/)	Terra/MODIS, Aqua/MODIS
	Aerosol products from ground-based sun photometer network since 1993. (http://aeronet.gsfc.nasa.gov/) and micro-pulse lidar network, since 2000 (http://mplnet.gsfc.nasa.gov)	AERONET, MPLNET
Global Water Cycle	Global precipitation data sets—monthly since 1979, daily since 1997, and every three hours since 1998. (http://precip.gsfc.nasa.gov)	TRMM, SSM/I, geosynchronous IR observations, TOVS/AIRS data, AMSR, AMSU and rain gauges
	Global land surface snow covered area products—swath, daily, 8-day, and monthly since 2000. (http://nsidc.org/data/modis/data_summaries/index.html#snow)	Terra/MODIS, Aqua/MODIS
	Global land surface snow water equivalent products—daily, 5-day, and monthly since 2002. (http://nsidc.org/data/ae_dysno.html)	Aqua/AMSR-E
	ISCCP cloud products since 1983. (http://isccp.giss.nasa.gov)	International constellations of weather satellites
	Global lake and reservoir levels for selected large (>100 km2) targets 10-day, 1992–present. (http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/)	TOPEX/Poseidon (NASA-ALT and SSALT/Poseidon-1 altimeters), Jason-1 (Poseidon-2 altimeter), OSTM/Jason-2 (Poseidon-3)
	Global gridded equal-area mass/water storage change anomaly fields—10-day, 2°. (http://grace.gsfc.nasa.gov/)	GRACE
	Global land surface soil moisture, vegetation water content and land surface temperature—2–3 day, 0.25° (http://geoservices.falw.vu.nl/)	SMMR, SSM/I, TRMM-TMI, AMSR-E

Table 8.3. (continued) List of ESD-supported long-term data records grouped by science discipline. Web links to sources or access points are shown in blue.

Science Area	Long-Term Data Records	Data Sources
Global Carbon Cycle	Satellite ocean color and biology data sets—global ocean chlorophyll concentrations, optical attenuation coefficients, and water-leaving radiances beginning in 1996. (http://oceancolor.gsfc.nasa.gov/)	Routine global data from OCTS, SeaWiFS, MODIS; Sparse global sampling from CZCS (1978-1986)
	Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) data set since 1981. (http://www.glcf.umd.edu/data/gimms/)	NOAA/AVHRR
	Land long-term data record (Land Surface Reflectance) since 1981. (http://ltdr.nascom.nasa.gov/ltdr/ltdr.html)	NOAA/AVHRR, MODIS
	Land surface albedo since 2000. (http://ladsweb.nascom.nasa.gov/)	Terra/MODIS, Aqua/MODIS
	Global Land Survey (GLS) USGS/NASA partnership to generate global satellite data sets to support measurement of Earth's land cover and rates of land cover change. Calibrated data sets exist for ~1975, ~1990, ~2000, and ~2005. (http://gls.umd.edu/)	Landsat MSS, TM and ETM+ (GSFC does the scene selections and ensures the radiometric and geometric calibration.)
Climate Variability and Change	Global radiation budget data sets—short-wave and long-wave radiative fluxes at the surface, top of atmosphere, and other levels since 1983. (http://isccp.giss.nasa.gov/projects/flux.html)	ISCCP data set combined with TOVS, SAGE, TOMS, and other satellites
	Total solar irradiance since 1978. (http://adsabs.harvard.edu/abs/2002AdSpR..29.1409F)	Nimbus-7 ERB, ACRIM I, II, ACRIM III, SORCE, SOHO/VIRGO
	Sea Ice extent, concentration, and type (ESMR since 1973; SMMR since 1978). (http://nsidc.org/data/nsidc-0051.html)	ESMR (extent only), SMMR, SSM/I, AMSR
	Ice sheet elevation changes since 1978. (http://nsidc.org/data/dems/index.html)	SeaSat, ERS-1/2, Envisat, ICESat, Airborne laser altimetry

researchers to study land cover and ecosystem change. A long-term measurement lead is needed to continue and build upon the activities for AVHRR, MODIS, and VIIRS that lead to the generation of key long-term land measurements. This scientist will serve as a focal point for developing and implementing systems for the production of a long time series of moderate-resolution land data records, the fusion of data products from moderate and fine sensors and from polar-orbiting and geosynchronous platforms. They will also refine algorithms for atmospherically correcting land surface reflectance and producing a long time series of measurements from moderate-resolution Earth-observing instruments, such as AVHRR, MODIS, and VIIRS.

Model Products

Near-real-time assimilation and model runs produce data products as well as forecasts at regular time intervals, distributed to NASA instrument teams, NASA field campaigns, and the scientific community. Long-range assimilation runs and model simulations produce multi-year retrospective analyses (reanalyses), as well as hindcasts of climate change and

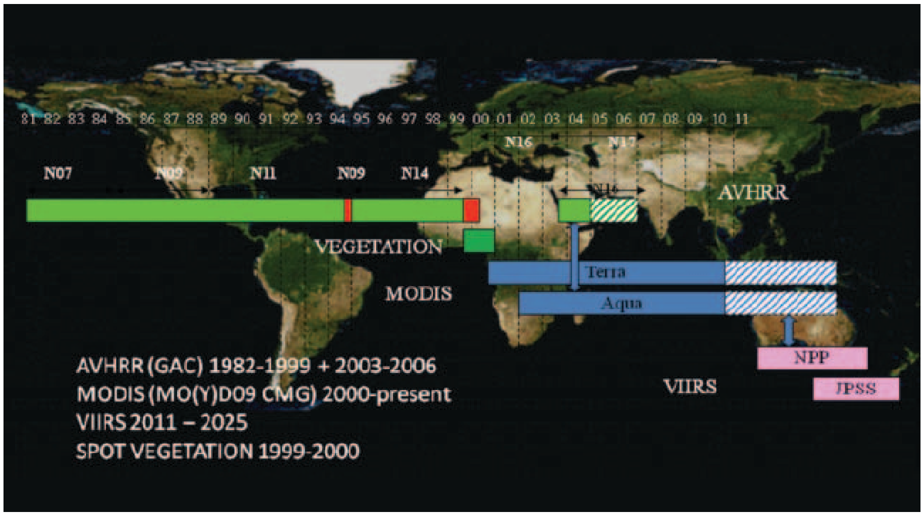


Figure 8.27. **This figure shows the time series of input source for generating the long-term land data records (LTDRs). The LTDR data system produces climate data records (CDR) using combination of mature and tested algorithms and best available AVHRR and MODIS data which can be extended to the VIIRS instruments on the NPP and JPSS satellites. A gap in the data record from AVHRR and MODIS for 1999-2000 will be filled using a SPOT Vegetation product generated by the European GEOLAND2 project.**

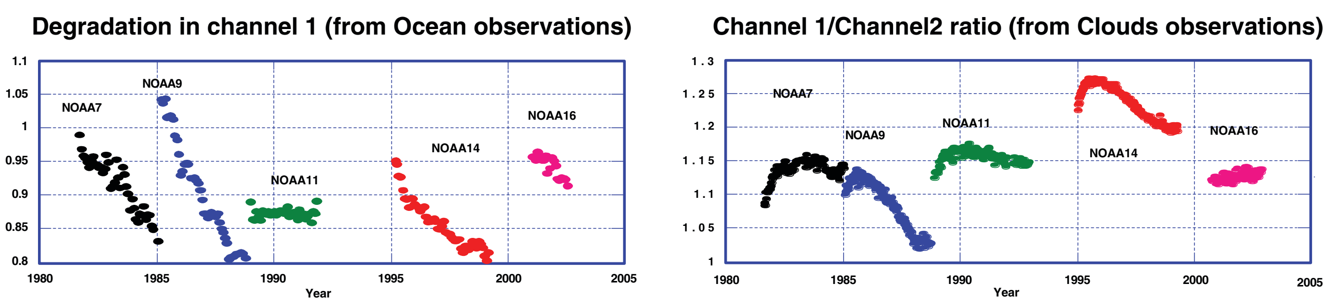
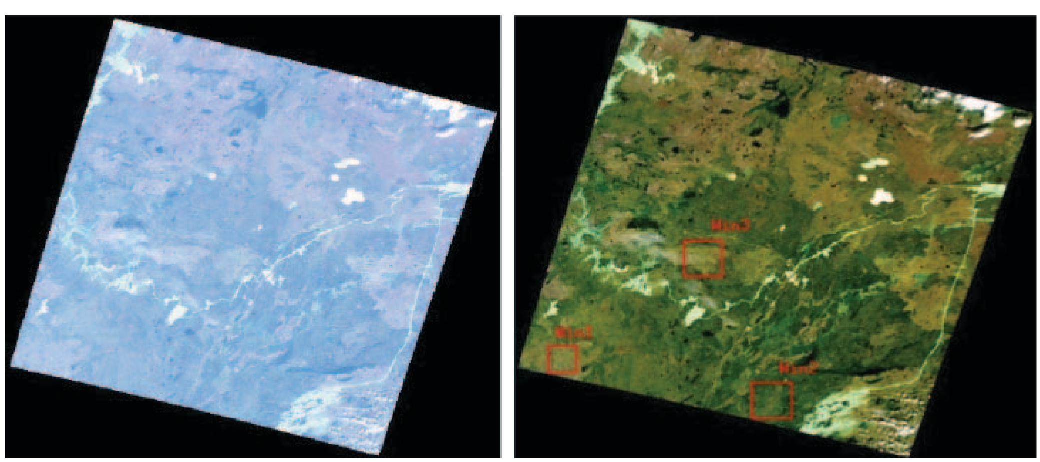


Figure 8.28. **The plot on the left shows the degradation in AVHRR channel 1 on different NOAA spacecraft. The plot on the right illustrates the channel1/channel 2 ratio used by the vicarious calibration approach in LTDR processing.**

Figure 8.29. **LTDR processing applies corrections for Rayleigh scattering, ozone and water vapor. The figure shows a spatial subset of the orbit data from AVHRR before and after the atmospheric correction step.**



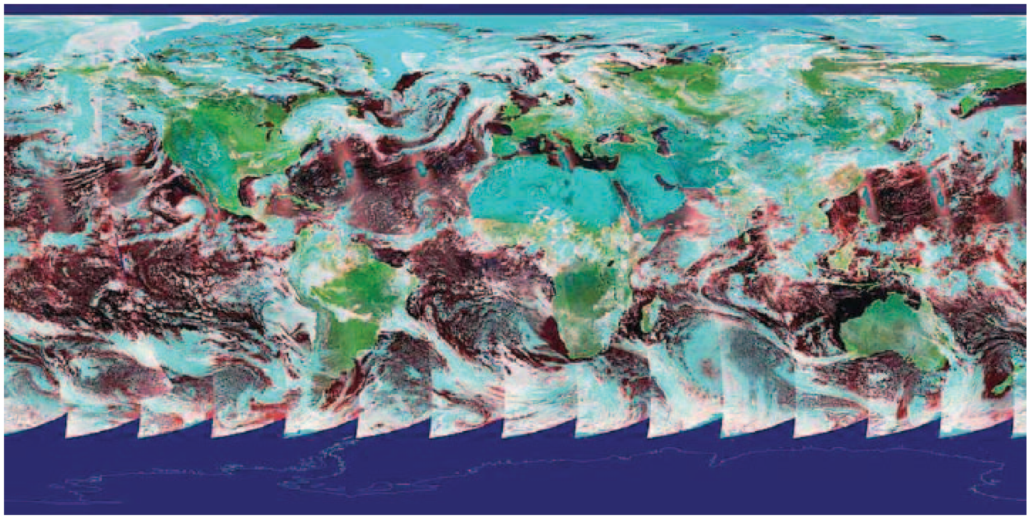


Figure 8.30. This image is a RGB composite of the surface reflectance product for day 193 of 2003 from the reprocessing of AVHRR (NOAA16) data by the LTDR data system. This surface reflectance daily global product is in a geographic projection at a resolution of 0.05 degrees, identical to that of the MODIS Climate Modeling Grid (CMG) products.

Table 8.4. Examples of ESD-supported modeling data products. Web links to the data sources and/or access points are shown in blue.

Modeling	Content
GEOS-5 (GSFC Earth Observing System Model, Version 5) analyses and forecasts (http://portal.nccs.nasa.gov/cgi-lats4d/opendap.cgi?&path=/GEOS-5)	Real-time meteorological data assimilation products and forecasts from GMAO.
GISS and GMAO contributions to 5th Coupled Model Intercomparison Project (CMIP5) (http://cmip-pcmdi.llnl.gov/cmip5/ and http://esg.nccs.nasa.gov/)	Climate integrations—present-day climate, decadal climate predictions, and long-term climate projections.
GLDAS (Global Land Data Assimilation System) (http://ldas.gsfc.nasa.gov/gldas/)	Global, multi-model land data assimilation products including forcing inputs 1° 1979–present (Noah, CLM, and Mosaic LSMs), 0.25° (Noah LSM), and 0.25° 2001-present (Noah LSM)
NLDAS (North American Land Data Assimilation System) (http://ldas.gsfc.nasa.gov/nldas/)	North America, multi-model land data assimilation products including forcing inputs 1/8 degree hourly 1979–present (Mosaic, with Noah, VIC, SAC soon)
LIS (Land Information System) (http://lis.gsfc.nasa.gov/)	Software framework for high performance, multi-model ensemble land surface modeling and data assimilation.
MERRA – Modern-Era Retrospective analysis for Research and Applications (http://disc.sci.gsfc.nasa.gov/mdisc/overview/index.shtml)	0.5° meteorological analysis from 1979-present available online through the GES MDISC.
NU-WRF (NASA Unified Weather Research and Forecasting Model) (https://modelingguru.nasa.gov/community/atmospheric/nuwrf/)	Superset of NCAR's WRF model, supporting coupling to NASA's existing models and assimilation systems such as GEOS-5 and LIS.
Goddard multi-scale modeling system (http://atmospheres.gsfc.nasa.gov/cloud_modeling/models_gce.html)	Local, regional cloud and precipitation data to support moist processes improvements in climate models.

projections for the future that are distributed to the community as a contribution to international projects.

Examples of ESD modeling products are given in Table 8.4. An example of MERRA product is shown in Figure 8.31.

Applications and Near Real Time Products

Near-real-time processing includes product generation, product acquisition, and validation in direct support of NASA science missions, science applications, and science product generation from external missions. Requirements for data manipulation and product generation are similar to those listed for Mission Data Products, with the difference that the products are generated and distributed typically within a 1-3-hour period. Examples of near-real-time products are given in Table 8.5. An example of a near-real-time product from the AIRS instrument is shown in Figure 8.32.

Near-real-time products from the MODIS instruments are widely used in monitoring and responding to disasters ranging from wildfires, floods, hurricanes to the Gulf of Mexico oil spill. Figure 8.33 illustrates MODIS imagery used in combination with other GIS layers at the federal government's geospatial information portal.

Data Discovery

The data discovery focus area consists of suites of software applications (see Table 8.6) that enable users to uniformly locate, access, and utilize resources (e.g., data, software, documents, image products, and services) from a collection of distributed product repositories and service providers. The typical functionality includes web services and other software to register, find, and access widely-distributed science products using a community-based data model; interactive tools to enable the selection, visualization, and analysis of data; and community-based science analysis libraries. Figure 8.34 shows the data and services search screen for the GCMD. Figure 8.35 shows various visualizations generated by the Giovanni data analysis and visualization tool.

8.6.2 High-Performance Computing

High-performance computing is the lifeblood of numerical modeling for climate, weather, the space environment, and solid-Earth science. High-performance computing also enables development and use of sophisticated data assimilation techniques, leading to enhanced exploitation of the observations made by Earth-observing satellites, the better to understand the Earth as a system, including the atmosphere, oceans, land, and the solid-Earth. The models we will deploy in the future will demand more computational power than those we use today. They will have more-complex physics, they will run at higher resolution, and we will need to make far more runs than we do today. In addition, we need to return results to the scientists faster than we do today.

Currently, NASA provides leading-edge computing platforms through two primary sources: the NASA Advanced Supercomputing (NAS) facility at NASA's Ames Research Center, and the NASA Center for Climate Simulation (NCCS) at GSFC. In 2008 Earth science applications used approximately 65 million processor hours of computing resources at these facilities, and produced over a petabyte of

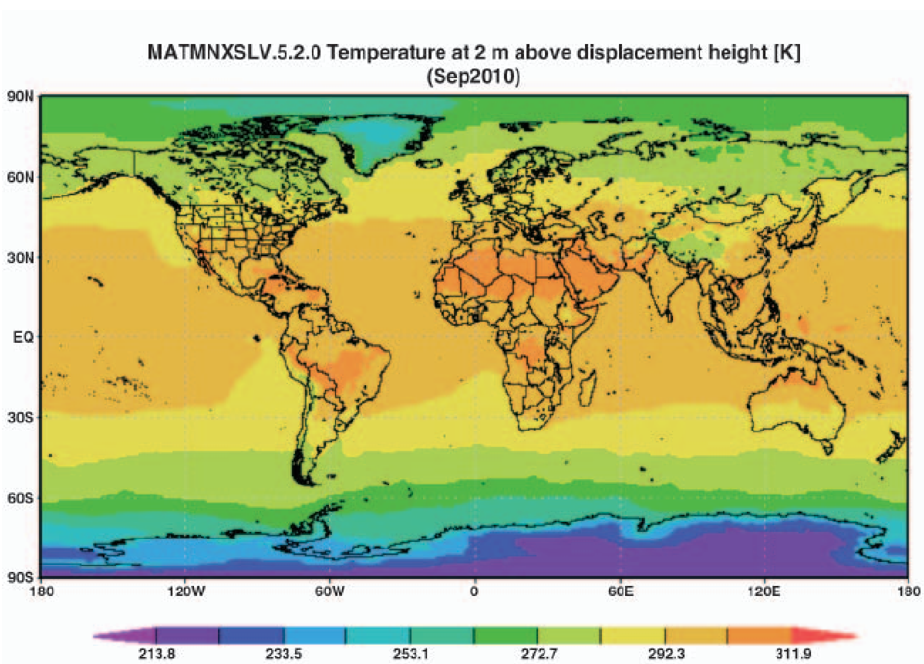


Figure 8.31. Example of a MERRA product (temperature at 2 m above displacement height).

scientific and observational data products. To execute the envisioned program of Earth science research in the next five years, substantially more computing power and data storage will be needed, along with enhanced capabilities to make NASA models and scientific data accessible to our research partners. To close the gap between the available and required computing, GSFC has recognized the NCCS as a core line of business. Center management is working directly with SMD at NASA Headquarters for additional support for computing. The NCCS has, in turn, worked closely with the ESD scientists to establish a computational environment that supports its needs. Hence, in addition to raw computational power, the NCCS has assembled (i) a visualization and analysis platform for post-processing and analysis of model simulations, and (ii) a data portal to facilitate sharing of model-derived data for collaborative science and the support of NASA field campaigns. It also provides a run-time environment that can be configured to support the real-time requirements of NASA missions and field campaigns.

A recent analysis of computational requirements for NASA Earth science estimates that by 2013 Earth science applications will require close to 900 million processors-hours annually, which is approximately 80 percent of the total SMD requirement. (For further details, see the Earth Science Modeling and Assimilation Panel Report of the SMD Requirements Workshop, August 2008.) However, given the advances made in the interim to facilitate simulations at high resolution (for example, a prototype of the GEOS-6 non-hydrostatic model has been run at 3.5 km globally on 14,000 processor cores in the NCCS), the 2008 estimate is already low. ESD scientists have asked for an additional 120,000 processor cores by 2016 to revolutionize what they are able to do with models to support NASA, including OSSEs to support mission design; an analysis of satellite observations that synthesizes data from atmosphere, land, and ocean into an integrated whole; and a prototype carbon monitoring system.

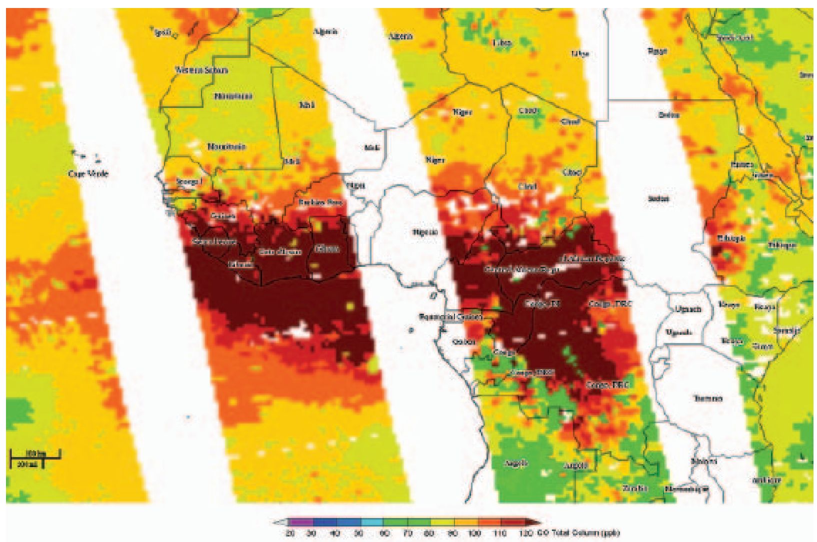


Figure 8.32. AIRS near-real-time (NRT) carbon monoxide (CO) retrieval showing very high concentrations, coming from the biomass burning in the savanna during the dry season.

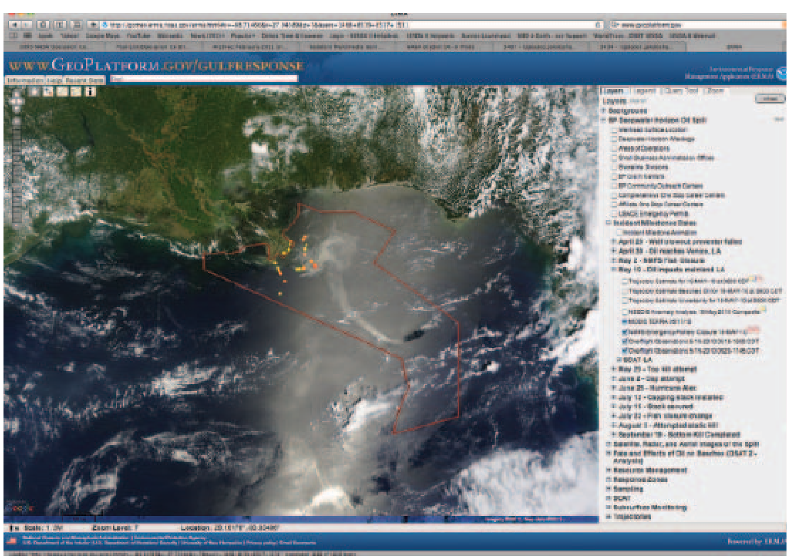


Figure 8.33. MODIS Terra true-color image of the Gulf of Mexico oil spill (acquired May 17, 2010) from the Rapid Response System integrated into the near-real-time interactive map on GeoPlatform.gov. Other GIS layers displayed include the fishery closure boundary (red outline) and aircraft oil observations (red, yellow, and orange dots). The Geospatial Platform, geoplatform.gov, was created by Presidential initiative to be a "one-stop shop" for geospatial information across the U.S. Federal government.

Table 8.5. Examples of ESD-supported applications and near-real-time products. Web links to the data sources and/or access points are shown in blue.

Other Capabilities	Content
GOES rapid data-product distribution system (http://goes.gsfc.nasa.gov/)	Continuous imagery of the western hemisphere.
LANCE (Land and Atmosphere Near real-time Capability for EOS) (http://lance.nasa.gov/)	MODIS, OMI, AIRS/MLS products and imagery.
LEDAPS (Landsat Ecosystem Disturbance Adaptive Processing System) (http://ledapsweb.nascom.nasa.gov/)	Landsat vegetation disturbance maps.
TRMM Flood / Landslide (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html)	TRMM
TRMM Ground Validation (radar) (http://trmm-fc.gsfc.nasa.gov/index.html)	Ground radar collection and processing.
AERONET (http://aeronet.gsfc.nasa.gov) MPLNET (http://mplnet.gsfc.nasa.gov)	Aerosol properties, planetary boundary layer height, cloud heights.

Table 8.6. Systems used for discovery and access to data and information spanning multiple science disciplines. Web links to the systems are shown in blue.

Data Discovery Capabilities	Content
CEOS IDN - Committee on Earth Observation Satellites International Directory Network (http://idn.ceos.org/)	Gateway to global Earth science data (supported by GCMD)
GCMD - Global Change Master Directory (http://gcmd.nasa.gov/)	Summary descriptions of 21,000+ Earth-sun science data sets and 2,000+ related services; 130+ data portals.
GES DISC – GSFC Earth Science Data and Information Services Centers—for example see A-Train Data Depot (http://daac.gsfc.nasa.gov/atdd/)	6 DISCs: Atmospheric Composition, AIRS, A-Train Data Depot, Hydrology, Modeling and Precipitation. Giovanni: data visualization and analysis application Mirador: text-based data search application.
NCCS Data portal – NASA Center for Climate Simulation's data portal access point (http://portal.nccs.nasa.gov)	Access to model and analysis data generated through NCCS resources.
NCCS Earth System Grid node (http://esg.nccs.nasa.gov/)	Access to the Earth System Grid gateway providing access to the archive of the 5th Coupled Model Intercomparison Project (CMIP5).
AERONET Data Synergy Tool (http://aeronet.gsfc.nasa.gov/cgi-bin/bamgomas_interactive)	Web portal containing data browsing tools for co-incident viewing of AERONET, MPLNET, MODIS, Back-Trajectories, model, and links to GIOVANNI.

Figure 8.34. GCMD home page with search screen for data and services

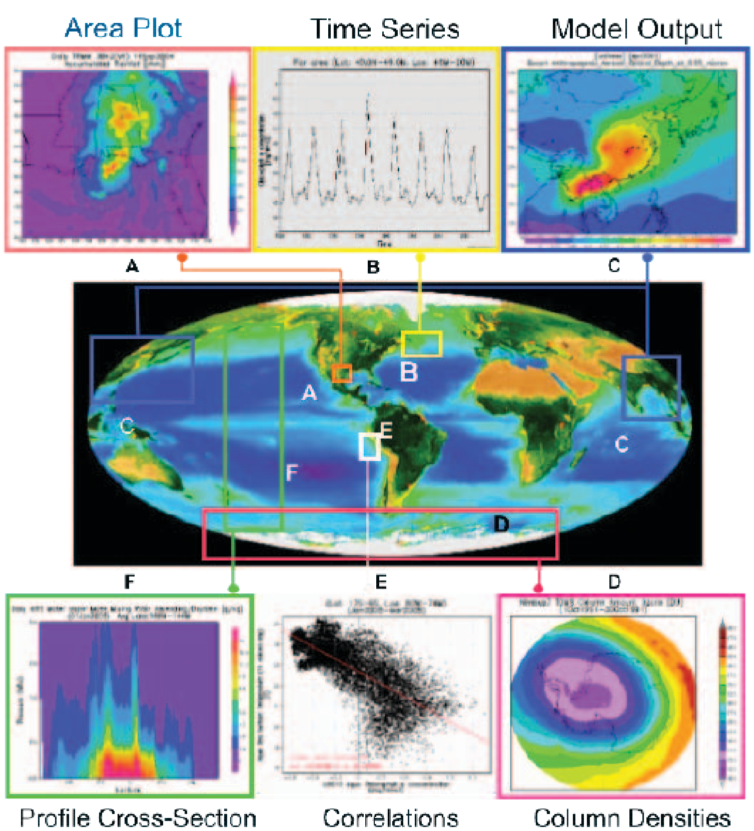


Figure 8.35. Giovanni provides a suite of statistical analysis and visualization tools for the comparison of regional and global datasets.

The NCCS has analyzed the science requirements, technology trends, and budget expectations to develop a roadmap for NCCS systems. With the existing budget guidelines, the NCCS envisions providing systems in 2013 with the following capabilities:

Computation

- 700 teraflops of peak processing power, estimated to require on the order of 50,000 cores at the anticipated future processor speed
- Enhanced software tools to exploit multi-core architectures
- Increased I/O rates to meet model execution requirements
- 100 terabytes of random-access memory
- Ability to support larger numbers of jobs, using on the order of 1,000 processors
- Ability to support very large jobs, using on the order of 15,000 processors

Storage

- 10 petabytes of disk storage to keep data online for 1 to 2 months
- Enhanced global file system
- 60 petabytes of archival storage
- Enhanced data management

Supporting services and systems

- Networks operating at 100 gigabits/second
- 250 teraflops for analysis and visualization
- Enhanced analysis and visualization tools
- Enhanced portals for external access to computing, data, and analysis

In addition, there is a need for a program of exploratory research into the application of advanced and innovative computing architectures to Earth science models. This includes the exploration of the potential of graphics processing units (GPU) and many-core processors to significantly increase throughput per dollar. In developing strategies for advanced technologies, the NCCS works closely with its science user community. For example, for GMAO has demonstrated a 30X speedup for the GEOS-5 dynamical core using Tesla GPUs compared with cores on the Discover Linux cluster. After discussions with GMAO and other users, the NCCS decided to implement a GPU test and development system in 2011 for algorithm and software testing and evaluation. If successful, the subsequent introduction of GPUs into the NCCS environment has the potential to dramatically change the total amount of peak processing power and numbers of cores.

To assist scientists in using the supercomputing facilities at GSFC and Ames, SIVO's Advanced Software Technologies Group (ASTG) provides a number of software and hardware support services to the community. The functions of SIVO are described in Chapter 8.6.3. ASTG services include Level 2 help desk support to user training, code migration, performance tuning, parallelization, algorithmic development, software engineering, and code modernization. SIVO works closely with the NCCS to assess code performance and system configuration as new hardware systems are integrated. Additionally, SIVO supports developmental projects to research beneficial impact of emerging technologies on Earth science code performance and advancing software tools to enhance community use of NASA models.

8.6.3 Advanced Software Development

Software Integration and Visualization Office (SIVO)

It is SIVO's responsibility to provide leadership to the Division and to the Directorate in addressing the issues of cost, risk, complexity, and performance of large numerical modeling codes. Between now and 2015, the biggest challenge will be adapting legacy codes to take advantage of new, complex architectures and customized architectural features. The growth of multicore systems and specialized GPUs presents a major challenge for scalability of Earth system modeling codes. Load imbalances and communication overhead will be exacerbated as parallelism requirements and the number of processors and cores increase. Additionally, the lack of a clear implementation paradigm will require multiple avenues of investigation to determine the most effective approach for our environment. By 2015, the computing software and hardware must be able to support a factor of two improvement in horizontal resolution.

The software changes required for exploiting newer architectures, as well as other improvements to scientific fidelity, will undoubtedly compound the growing costs associated with maintaining and extending legacy software within the Division. SIVO will continue work with modeling groups to encourage improved software practices within the Division, including adherence to community coding standards and frameworks, robust testing, and adoption of appropriate software development tools.

Another aspect of SIVO is the Scientific Visualization Studio (SVS), which supports ESD outreach and education efforts by producing sophisticated and dramatic visual products from Earth science data. Such products enable collaboration with education and media entities, such as museums and documentarians, providing communication pathways to a broad public community.

9. Instruments, Technology, and New Missions

The Earth Science Line of Business (ES LOB) is responsible for identifying and investing in technologies that directly support the development of new measurement concepts from all vantage points necessary to study our planet. To that end, ESD scientists work closely with engineers to develop new measurement concepts and design new instruments for space, airborne, balloon, and ground observations.

Ground-based systems provide surface or near-surface measurements and balloon and airborne platforms facilitate viewing processes such as precipitation, cloud systems, surface vegetation, and water or ice from a high-altitude vantage point and with high spatial and/or spectral resolution. Major field campaigns supported by ESD frequently need observations at multiple levels and thus require simultaneous ground, air, and space observations. As a result, a substantial component of our efforts is focused on developing in-situ and suborbital (aircraft, balloon, and UAV/UAV) instruments in order to demonstrate the measurement and the maturity of the technology. This substantially reduces the risk to NASA in introducing new measurements and technology into future observations.

9.1 Instruments

Funding for technology development activities is usually obtained through a competitive process. For low Technology Readiness Level (TRL) activities, funding may come from broadly competed programs, directly from existing instrument programs, or from programs funded internally by GSFC, such as IRAD. As technology progresses beyond low TRL, scientists, and engineers may compete for potential funding from one of the Mid-TRL technology programs available via the ROSES solicitation such as IIP or AITT or through GSFC IRAD.

Technological advances are typically needed to make new measurements and to provide improved spatial, spectral, and temporal characteristics, or the instrument may need to operate in a new environment or from a different vantage point. Technology improvements therefore occur within the instrument, the spacecraft, or as part of information technology in support of the science.

The need for improvements in temporal coverage and update rates has driven many of the advanced observing scenarios to take advantage of new vantage points such as Geosynchronous/Geostationary Earth Orbit (GEO) and L1/L2 orbits. These new vantage points require additional improvements in Signal-to-Noise Ratio (SNR) of our detectors, aperture size, greater on-board processing capability, and more efficient and more powerful active measurement components (such as lasers) than traditional vantage point locations.

Current areas of ES-related instrument development are summarized below:

Lidars

Laser-based, or Lidar, instruments are an essential part of on-going and future Earth observations. The Geoscience Laser Altimeter System (GLAS) on ICESat and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) laser on CALIPSO have clearly demonstrated the tremendous advancement in measurements that can be provided with lidar-based space instruments, and MPLNET has demonstrated the capability of continuous ground-based lidar network observations. The NRC Decadal Survey has identified a number of essential measurements and missions (e.g., ICESat II, DESDynI, ASCENDS, ACE, and LIST) that are expected to be accomplished by lidar-based instruments. These missions are described in more detail in Chapters 9.5 and 9.6.

GSFC is currently investing in the design and development of lidars for topographic information, cloud and aerosol height/properties, trace gas concentrations, and wind speed and direction measurements. We are also addressing the technological challenges associated with the limited laser power and diode lifetime of these types of active instruments. The next five years will see improved capabilities in resolution and vastly improved transportability, including application to UAV platforms.

Microwave Remote Sensing

The capabilities of microwave instruments such as TRMM Microwave Imager (TMI), the ER-2 Doppler radar (EDOP), the NASA Polarization radar (N-POL), and radiometers including Airborne Earth Sciences Microwave Imaging Radiometer (AESMIR), Conically Scanning Millimeter-wave Imaging Radiometer (CoSMIR), and Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR) have had profound effects on Earth Science measurements. Through the development and application of these instruments we have fundamentally changed our ability to observe and understand ocean salinity, precipitation, soil moisture, cold land processes, sea ice, and ocean wind measurements. Present and proposed future missions are based on these developments. Our ongoing support of future space missions, including Aquarius, GPM, and SMAP requires planning for anticipated retirements in the area of precipitation radars operating in space, and on aircraft and the ground. Our present observational capabilities include innovative scanning aircraft microwave radiometers operating through the 1 – 1000 GHz spectrum, and transportable radars (EDOP, N-POL), scatterometers, and radiometers. The last five years have seen significant advances in these instruments including digital beam forming, synthetic aperture radiometry, multiple frequency/polarization radars, SAR and interferometric radars, that greatly extend the capabilities of these systems. Additionally, there is a continued move to smaller and more flexible airborne platforms, including UAVs. Our remote sensing measurements will continue to be buttressed by our focused in-situ sensing program, with its innovative UAV program and autonomous ocean-sensing systems.

ESD instruments are available on a cost-reimbursed facility basis in support of NASA scientific research and have been used by our sister agencies, including NOAA, DOD, and USGS, as well as by academia.

Visible/UV and Near IR

Historically, ESD has developed sensors in the UV-visible range, such as for the SBUV and TOMS instruments and Solar and Heliospheric Observatory (SOHO)/Coronal Diagnostic Spectrometer (CDS). However, new measurements from Low Earth Orbit (LEO), GEO, and the Libration points require better spatial and spectral observation and drive the need for better and larger detector systems. New technology developments include UV-visible polarimeters, micro-bolometer, and Quantum Well Infrared Photodectors (QWIPS) sensors. Large-format, fast readout detectors from the visible to the extreme ultraviolet (EUV) are central to remote imaging and spectroscopy of the solar atmosphere. The Division has extensive experience with EUV spectrographs and detectors and has proposed spectrograph concepts for an L-1 Earth-Sun mission.

9.2 New Platforms and Vantage Points

NASA is always seeking to push the envelope of technology and observations. This section discusses the potential opportunities of using new airborne platforms and new space vantage points to make observations.

9.2.1 Unmanned Aircraft Systems

Airborne instruments and observations have always played an essential role in NASA Earth Science investigations. Aircraft missions give the opportunity to develop and demonstrate new instruments and measurements much less expensively than a space mission. This substantially reduces NASA's risk in introducing new measurements and technology into future observations. Aircraft campaigns provide an essential role in the development of new algorithms for satellite instruments, plus the calibration and validation of satellite measurements.

Unmanned Aircraft Systems (UASs) provides new observational capabilities that are complementary with current and future satellite missions. Currently, there is a significant observation gap between the high resolution capabilities of aircraft measurements, which are limited in spatial and temporal coverage, and satellite observations, which provide a global

Figure 9.1. NASA Global Hawk

view, but often without adequate vertical and horizontal measurement resolution necessary to discern important fine-scale features. A high-altitude and long-endurance UAS fills this critical observation gap and expands the observational domain with high-resolution data combined with near-global coverage. UASs, developed for military reconnaissance, have large payload capacity, long duration, and high altitude capabilities. Operational UAS flights could impact a broad range of scientific applications, including synoptic weather systems, hurricanes, air quality, stratospheric ozone, ozone depleting substances, greenhouse gases, ice sheets, forest fires, droughts, and storm damage, as well as satellite validation. Additional flights could be allocated for research tasks, including targeted flights with payloads for specific science questions, satellite instrument development, and support of U.S. Government science and applications missions.

A developing NASA UAS program will become a new and vital component of the emerging Global Earth Observation System of Systems (GEOSS) 10-year implementation plan, which is now supported by over 60 countries around the world. In addition, a major UAS program would be similar in cost to a modest cost five-year satellite mission, but the UAS effort will also be ongoing and will address a broader range of high-priority science missions, whose societal benefits would greatly improve the quality of life on our planet. GSFC ESD scientists have a number of aircraft instruments developed for the NASA ER-2 that are being used on UASs, along with instruments that are being specifically developed for UASs.

In April-May 2010, the Aura Project prototyped the use of UASs (the NASA Global Hawk) for validation. The Global Hawk Pacific (GloPac) mission flew a mix of remote sensing and in-situ instruments for sampling stratospheric air and tropospheric air pollution, while providing validation observations for the A-Train satellites. In addition, the Hurricane Science Research Program sponsored the Genesis and Rapid Intensification Processes (GRIP) mission in Aug.-Sep. 2010 that focused on hurricane genesis and intensification in the western Atlantic basin. GRIP utilized the GSFC HIWRAP instrument. GSFC is now involved with two missions on the NASA Global Hawk as part of the Venture Class of science missions: Hurricane and Severe Storm Sentinel (HS3), and the Airborne Tropical TRopopause Experiment (ATTREX).

9.2.2 Geostationary Orbit

Geostationary orbit has long been exploited for weather monitoring, but it is underused with regard to the EOS class multispectral sensors developed for LEO. There are some distinct advantages to the geostationary orbit—sensors in geostationary orbit can make high time resolution measurements, e.g., every 15 minutes over the same spot while Sun synchronous low Earth orbit satellites can make two measurements per day. GEO allows good monitoring of rapidly changing conditions such as occur during severe weather outbreaks and diurnal pollution episodes. Since GEO is 60 times further from the Earth than a typical LEO, larger apertures for sensors are needed to achieve the same ground resolution as from LEO. On the other hand, GEO satellites can stare at the same spot for a longer period and thus achieve equivalent or better signal-to-noise than a low Earth orbit sensor can achieve. GEO is naturally situated to observe the high-energy particles and field fluctuations in the middle of the Earth's magnetosphere. GEO is also a vantage point for continuously monitoring solar EUV and X-ray activity. GEO sensors and satellites are technically challenging because they need to be compact, power-conserving, lightweight, and long-lived.

NOAA is now procuring the next generation of geostationary operational environmental satellites (GOES-R) to launch in 2015. The entire NOAA GOES-R activity (program office, flight project, and ground system project) is hosted at GSFC and jointly staffed by NASA and NOAA. Significant advancements in GOES-R instrumentation will include an EOS-class imager and a lightning mapper. The NRC has also called for a demonstration of hyperspectral sounding from GEO, and there is space for such an instrument on the GOES-R platforms should funds be made available. ESD provides the Project Scientist for the existing geostationary satellites and for the GOES-R effort.

9.2.3 Venture Class Concepts

In addition to the missions identified in the NRC Decadal Survey and described in 5.3, the Earth Science Line of Business is developing a series of Venture Class instrument and mission concepts as part of NASA's Earth Science Directorate's Earth Venture (EV) Program.

The EV Program was created in 2009 as a new element within the ESSP Program. EV consists of a series of regularly solicited, competitively selected Earth Science investigations. The EV program intends to solicit proposals on an on-going basis with current plans for a solicitation every two years that will include suborbital science investigations, instruments of opportunity, and stand alone space missions. EV missions are intended to be innovative, integrated, and hypothesis or scientific question-driven approaches to Earth system science, involving temporally sustained data acquisition.

ESD submitted a number of proposals in response to the first EV solicitation for suborbital investigations that was released in July 2009. The ESD proposals addressed a variety of science applications to a number of national needs. Specific areas of proposed investigations included cryosphere science (permafrost change), biosphere science (ecosystem structure), and atmospheric chemistry and dynamics (hurricane research and monitoring).

The Division, in collaboration with other NASA Centers and the community, continues to actively engage in the development of instrument and mission concepts for future EV solicitations. It is anticipated that the next solicitation will be for stand-alone space mission concepts on the order of $150M per mission. A separate solicitation for Instrument development, EV-I, is also expected in 2011 with a cost cap of $90M per instrument.

9.2.4 International Space Station Utilization

The International Space Station (ISS) may also serve as a viable platform for Earth observation. To that end, ESD has identified several instrument concepts including lidar for aerosol and carbon measurement, hyperspectral imaging for carbon monitoring, and interferometry for greenhouse gas measurement. GSFC and ESD will continue to develop concepts for ISS utilization that take advantage of our unique instrument development and science capabilities.

9.3 Operating Missions

Terra

Launched in December 1999, the Terra spacecraft and its compliment of five instruments are functioning well and continue to provide the scientific community with over 70 core data products in multiple science focus areas. Downloads of Terra data tripled between 2008 and 2010 with a record 133+ million data files downloaded in 2010. All five Terra instruments

(ASTER, CERES, MISR, MODIS, and MOPITT) have made substantial contributions during the past several years. In addition to the continued generation of high-quality core science data products, the project made Terra data available to numerous relief efforts including responses to the Haitian earthquake, the Gulf of Mexico oil spill, and the Eyjafjallajökull volcano. Science accomplishment highlights include the release of ASTER's new Global Digital Elevation Model, which is the most complete, consistent high-resolution global topographic data set ever made available to the public. CERES released a new data product of TOA within-atmosphere and surface radiative fluxes at 3-hourly and monthly time scales. This data product involves the highest level of data fusion using CERES, MODIS, five geostationary instruments, meteorological data assimilation, and aerosol assimilation. MISR made refinements in the cloud-top height, cloud motion vector, and aerosol type retrievals, expanded the Plume Height Climatology Product beyond North America, and released two new Level 3 products. MODIS continues to provide data to the science community and national needs efforts through the MODIS Rapid Response, and implemented major calibration improvements for its ocean color spectral bands at short wavelengths and VIS spectral bands critical to deep blue and aerosol products. The new Terra ocean color data products are now suitable for comparison with Aqua MODIS and SeaWiFS. MOPITT released its "Version 4" (V4) tropospheric CO product and completed the "Version 5" (V5) product. The MOPITT V5 product is the first satellite product for CO to exploit both thermal-infrared (TIR) and near-infrared (NIR) radiances, resulting in much greater sensitivity to CO sources near the surface compared to current satellite products for CO. The fully functional lifetime of the Terra Mission is projected to be seven more years (2018) based on the battery anomaly. There is enough fuel for eight more years.

Aqua

The Aqua spacecraft, now well over two years beyond its design lifetime, continues to do extremely well. The spacecraft and five of its six Earth-observing instruments continue in operation, with data relayed to the Earth, both through direct broadcast and through downlinks to the polar ground stations. These Aqua data are being used in immediately practical applications by such groups as weather forecasters and the U. S. Forest Service, and by scientists around the world. Highlights within the past year include the use of Aqua data to examine the April 2010 Deepwater Horizon oil spill in the Gulf of Mexico, and the April 2010 eruption of the Eyjafjallajökull volcano, plus the scientific advance of obtaining stratospheric carbon dioxide information from Aqua data, adding to the information earlier obtained regarding mid-tropospheric carbon dioxide. Projections now suggest that the Aqua mission may be able to continue to 2020 or perhaps beyond.

Aura

Aura was launched on July 15, 2004, and continues to make tropospheric and stratospheric measurements of ozone and other constituents that are important to composition and climate. Aura carries four instruments: the Ozone Monitoring Instrument (OMI), the Microwave Limb Sounder (MLS), the Tropospheric Emission Spectrometer (TES), and the High Resolution Dynamics Limb Sounder (HIRDLS). OMI, MLS, and TES all presently continue their observations. Recently, OMI measurements of ash and sulfur dioxide were used to track the eruption of Eyjafjallajökull volcano in Iceland. This eruption in spring 2010 disrupted air travel in Europe for weeks because volcanic ash is destructive for jet engines. MLS observations show the clear imprint of El Niño on the composition of the upper troposphere. TES measurements of water (H_2O) and heavy water (HDO, where one H atom is replaced by a deuterium molecule) are being used to understand moisture recycling in the tropics. Although HIRDLS is not presently operational, prior measurements of the cirrus cloud distribution in the tropics are being used to understand how heating associated with these clouds enhances vertical transport.

Landsat

Landsat-7 and Landsat-5 continue to operate successfully and acquire critical data on Earth's land environment. During CY 2010, Landsat-5 and Landsat-7 acquired over 128,000 images for the USGS archive, and delivered an additional number to International Cooperator stations around the world. The fact that Landsat data have been freely available (since 2008) has spurred a dramatic increase in the volume of downloads, and in the scale at which the data are being applied to Earth Science problems. Of particular note have been several recent papers focusing on forest cover change, in preparation for implementation of UNFCCC REDD (Reducing Emissions from Deforestation and Forest Degradation) program:

- Hansen et al (2010) used MODIS and Landsat in combination to provide the first satellite-based estimate of gross forest cover loss around the globe.
- Giri et al (2010) provided the first satellite-based map of global mangrove extent, and ecosystem critical for coastal fisheries.
- Gibbs et al (2010) quantified the degree to which new agricultural land around the globe is derived from forest clearing.

The Global Land Survey (GLS) activity at GSFC continues to support these global mapping initiatives by providing half-decadal, cloud-free global data sets culled from the "best of the archive." As one measure of the mission's science productivity, over 700 peer-reviewed articles published during 2009 used or discussed Landsat, as did 135 presentations at the Fall 2010 American Geophysical Union Meeting.

On the technical front, USGS, the Land Cover Project Science Office at GSFC, and South Dakota State University collaborated on producing the first historical intercalibration of all Landsat sensors, extending from Landsat-7 ETM+ back to the MSS sensor aboard Landsat-1 (launched in 1972). By cross-walking calibrated observations from the Landsat-7 era to earlier sensors, a 38-year record of calibrated radiances can now be generated for any site on Earth.

Landsat-5 continues to operate successfully, but shows signs of its age. During 2010, the current within the X-band transmitter travelling wave tube showed anomalously high readings, threatening an overcurrent situation. Although changes made by USGS to instrument operations have stabilized the current, the future longevity of the mission is unknown. The final delta-inclination maneuver for Landsat-5 was performed in October 2010, and current forecasts suggest that the last usable science data will be collected during 2014. Also during 2010 the Landsat teams from NASA and USGS participated in studies to avoid conjunctions between the NASA A-Train satellites and Landsat-5 at the poles.

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TRMM

The Tropical Rainfall Measuring Mission (TRMM), launched in late 1997, is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA). The first-time use of both active and passive microwave instruments and the precessing, low inclination orbit (35°) have made TRMM the world's foremost satellite for the study of precipitation and associated storms and climate processes in the tropics. TRMM instruments include the first and only precipitation radar in space, the TRMM microwave imager, a visible and infrared scanner, and a lightning imaging sensor. TRMM's original goal was to advance our understanding of the mean distribution of tropical rainfall and its relation to the global water and energy cycles. As the TRMM mission has now continued into its 14th year, the science objectives have extended beyond just determining the mean precipitation distribution, but have evolved toward determining the time and space varying characteristics of tropical rainfall, convective systems, and storms, and how these characteristics are related to variations in the global water and energy cycles. Many significant scientific accomplishments have already come from TRMM data, including reducing the uncertainty of mean tropical oceanic rainfall; a documentation of regional, diurnal, and inter-annual variations in precipitation characteristics; the first estimated profiles of latent heating from satellite data; improved climate simulations; increased knowledge of characteristics of convective systems and tropical cyclones; and new insight into the impact of humans on rainfall distributions. The availability of real-time TRMM data has led to significant applications and fulfillment of national operational objectives through use of TRMM data, primarily in the monitoring of tropical cyclones, in hydrological applications and in assimilation of precipitation information into forecast models. The TRMM satellite and its instruments are in excellent shape and there is sufficient station-keeping fuel on board to potentially maintain science operations until 2014 or later.

ICESat

ICESat (Ice, Cloud, and land Elevation Satellite) is the benchmark Earth Observing System mission for measuring ice sheet elevation changes, sea ice thickness changes, cloud and aerosol heights, as well as land topography and vegetation characteristics. From 2003 to 2009, the ICESat mission used a state-of-the-art laser altimeter (the Geoscience Laser Altimeter System) to provide multi-year elevation data needed to determine ice sheet mass balance of the Greenland and Antarctic ice sheets, as well as cloud property information, especially for stratospheric clouds common over polar areas. It also provided topography and vegetation data around the globe.

The ICESat mission met and exceeded all of its mission success criteria, and the ICESat data set continues to enable key scientific results in cryospheric, as well as biospheric, sciences.

ICESat was successfully decommissioned from operations Saturday, August 14, 2010, at approximately 17:37:00 Greenwich Mean Time (GMT). As part of the final stage of mission decommissioning, the flight operations team passivated the spacecraft in compliance with NASA policy and regulations that seek to "minimize the creation of orbital debris by government and non-government operations in space in order to preserve the space environment for future generations." To passivate ICESat, the team sent and activated a series of commands previously stored in the on-board computer to remove all forms of stored energy from the spacecraft. The team verified successful passivation after confirming negative acquisition of signal by ground network tracking stations. Re-entry information will be issued by the NASA Orbital Debris Program Office from data provided by the United States Space Surveillance Network.

Congratulations to the ICESat team for a successful seven years of operations.

GOES

Geostationary Operational Environmental Satellite (GOES) is NOAA's line of operational weather and communications satellites. "Health and safety" is its mission.

The current GOES (fourth) generation of satellites has been successfully launched in the last few years, with one operating as GOES-EAST, and the other two parked as on-orbit spares, to be used during the first half of this decade. All systems are operating. The ground system at GSFC that offers calibrated, full-resolution GOES imagery on the web is tapped for 250 GBytes/day.

The next (fifth) generation GOES-R/S instruments and satellites have begun construction for launch in 2015/2016. The next generation will sport an advanced imager that has factors of 2 to 5 improvements in spatial resolution, speed, spectral coverage, noise, and calibration accuracy. This will enable dozens of new and improved data products for NOAA weather forecasts. A real-time lightning mapper is being added to the observing suite, which will be capable of reporting thousands of flashes per second over the entire western hemisphere, locating severe storms, particularly tornadic events, as they begin.

SORCE

Since its launch in January 2003, the Solar Radiation and Climate Experiment (SORCE) has achieved its goal of simultaneously measuring total solar irradiance (TSI) and solar spectral irradiance (SSI) in the 0.1-27 nm and 115-2400 nm wavelength ranges with unprecedented accuracy and precision. SORCE has successfully completed its five-year core mission (January 2003 to January 2008) and is now in the fourth year of its extended mission. SORCE has accomplished unique new observations of the solar irradiance and has improved the understanding of solar radiative forcing of Earth's climate and atmosphere during the descending phase of solar activity cycle 23 and now into the rising phase of solar cycle 24.

Variations in the Sun's total and spectral irradiance impose key natural forcings on the climate system, and the solar ultraviolet (UV) radiation is a key driver for atmospheric photochemistry and composition. Accurate and precise long-term records of TSI and SSI are thus important components of NASA's Earth Science program [e.g., NASA Science Plan, 2010]. Current TSI and SSI measurements by SORCE, future TSI measurement by Glory, and planned TSI and SSI measurements by JPSS TSIS are essential measurements for our national climate program as discussed in the *NRC Earth Science and Applications from Space* [2007].

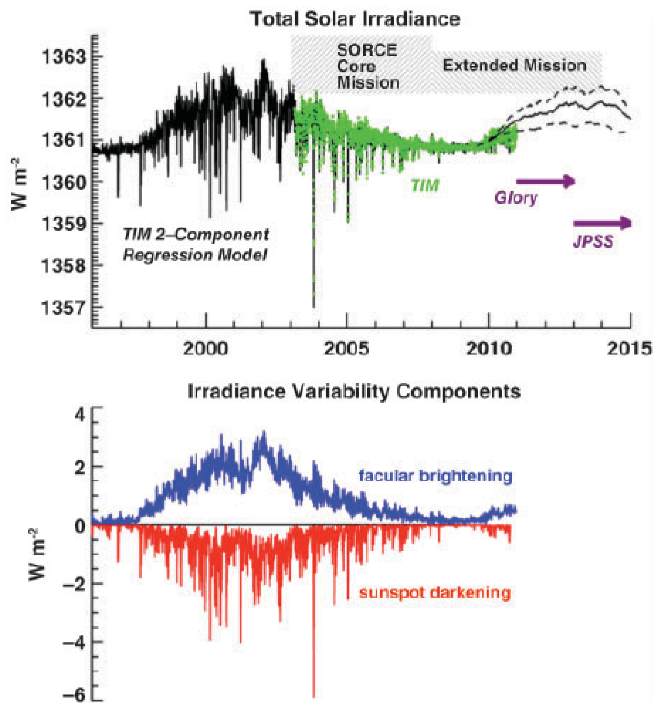


Figure 9.2. LASP Total Solar Irradiance Measurements. SORCE has tracked the decline of solar irradiance in solar cycle 23, through the solar cycle minimum in 2008, and now into the rising phase of solar cycle 24. TIM measurements of total irradiance are indicated by the green symbols. From these observations, the sunspot and facular sources of irradiance variations have been identified and shown in the lower panel. The dashed curves correspond to solar activity predictions that are 40 percent higher and lower than in cycle 23.

Major accomplishments of the SORCE mission during the past two years include:

- The accurate value of total solar irradiance during the 2008 solar minimum period is 1360.8±0.5 W m^{-2} according to measurements from the SORCE TIM and a series of new radiometric laboratory tests. This value is significantly lower than the canonical value of 1365.4±1.3 W m^{-2} established in the 1990s, which energy balance calculations and climate models currently use [Kopp and Lean, 2010].
- The fundamental discovery that the solar spectral irradiance in the visible does not vary in phase with the TSI over the solar cycle. This necessitates new studies in solar heating in Earth's atmosphere and at the surface [Harder et al., 2009; Cahalan et al., 2010; Haigh et al., 2010].
- Establishment of reference spectra for the 2008 solar cycle minimum using simultaneous observations throughout the X-ray, UV, visible,

- and IR regions and with the total irradiance [Woods et al., 2009].
- Commencement of a new and unique database of near UV, visible, and near infrared solar spectral irradiance [http://lasp.colorado.edu/sorce/].
- Continuation with the UV irradiance database implemented thus far by SBUV, SME, and UARS [http://lasp.colorado.edu/lisird/].
- New, improved models of solar irradiance variations, including forecast capabilities, for investigating physical sources of solar variability for use in studying past and future climate change [Fontenla et al., 2009].

During an extended mission for FY 2012-FY 2014, as solar activity increases during cycle 24 (see Figure 9.2), SORCE will:

- Extend the SORCE irradiance measurements to overlap with the Glory (launched planned for February 2011) and the European Space Agency's PICARD/PREMOS TSI measurements (launched June 15, 2010).
- Characterize and understand solar irradiance variations during the ascending phase and maximum of solar cycle 24, which is predicted to occur in 2013 and to be low as compared to cycle 23.
- Validate on-orbit tracking of instrument responsivities as a result of their operation in a new environment of increasing, rather than decreasing, solar activity.
- Extend and improve the long-term TSI and SSI records from the combination of SORCE irradiance measurements with previous measurements, some dating back to 1978.
- Improve understanding and characterizations of the sources of solar total and spectral irradiance through continued development of solar irradiance models that are constrained and validated with the precise SORCE observations (2003-2014) over a complete solar cycle.

9.4 Airborne Missions

GRIP

The Genesis and Rapid Intensification Processes (GRIP) field campaign was the fifth NASA airborne field campaign dedicated to improving our understanding of tropical storms in the Caribbean and western Atlantic Ocean. GRIP was specifically aimed at understanding the formation of hurricanes (genesis) and their transition to intense storms, sometimes in a matter of 6-12 hours (rapid intensification). Three instrumented NASA aircraft were used: the DC-8, the WB-57, and for the first time, the NASA Global Hawk with 26-hour flight endurance. The DC-8 payload had seven remote sensing or in-situ instruments, whereas the primary focus was on remote sensing with the WB-57 (microwave radiometer), and the Global Hawk (radar, radiometer, and lightning sensor). The aircraft and payloads were designed for studying both the precipitation regions associated with developing storms and the larger scale storm environment. GRIP was closely coordinated with two partner field programs: the NOAA Hurricane Research Division Intensity Forecasting Experiment (IFEX) and the National Space Foundation (NSF) PRE-Depression Investigation of Cloud-systems in the Tropics (PREDICT).

There were a number of scientific and technical accomplishments in GRIP. The GRIP field campaign was successful in observing the genesis of two storms (Tropical Storm Gaston and Hurricane Earl) with aircraft flights, and captured the rapid intensification of Hurricane Earl to Category 5, and Hurricane Karl from storm stage to Category 3 and landfall. Early on during GRIP, the Global Hawk conducted the first flights ever of an unmanned aircraft over a dissipating tropical storm (Frank) and then a hurricane (Earl). The plane then went on to make 20 crossings of Hurricane Karl, and an additional high number of crossings of Hurricane Matthew. During these flights, there was often close coordination between the NOAA, NSF, and NASA aircraft.

Drs. Scott Braun and Gerald Heymsfield were Mission Scientists in GRIP. GSFC flew the new High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP, PI: Gerald Heymsfield) on the Global Hawk. A number of other GSFC Mesoscale Atmospheric Processes Branch personnel supported GRIP forecasting and DC-8 flights (Ms. Amber Reynolds, Dr. Jason Pippitt) and the HIWRAP deployment (Drs. Lin Tian and Steven Guimond).

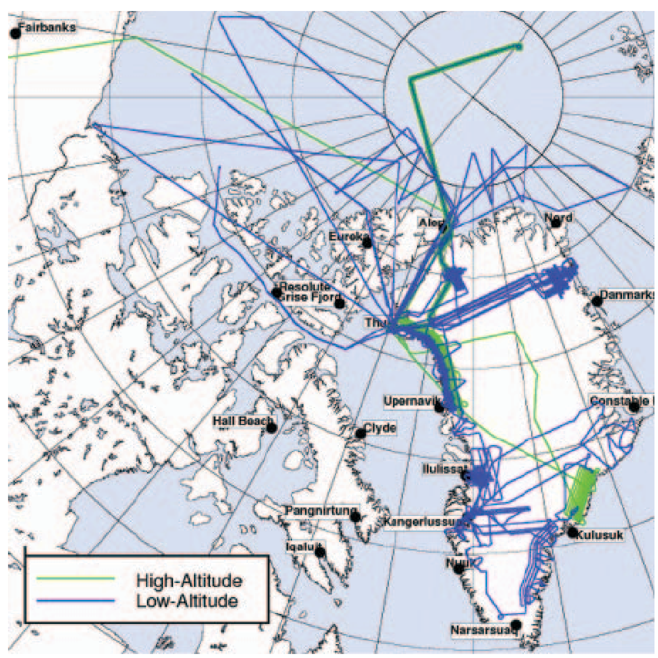


Figure 9.3. Operation IceBridge Arctic 2010 Campaign's ice paths

Figure 9.4. DC-8 crew members Leo Salazar and Scott Silver work in blowing snow on the ramp shortly before takeoff from Thule Air Base for the fifth science flight of the 2010 Arctic campaign of Operation IceBridge. Credit: Michael Studinger

GloPac

The Global Hawk Pacific Mission (GloPac) was the first demonstration of the Global Hawk unmanned aircraft system (UAS) for Earth science. A principal GloPac goal was to demonstrate that the Global Hawk could be operated routinely to obtain science-quality data over remote atmospheric regions. A payload of 11 instruments was integrated onto the Global Hawk in March 2010. Initial test flights were conducted on April 2nd and 7th, followed by full science flights on April 13th, 22nd, and 30th. The science flights ranged in duration from 14 to 28 hrs, reached cruise altitudes up to 65,000 ft (19.8 km) and covered distances between 4600 nmi (8520 km) and 9700 nmi (17,960 km). The Global Hawk reached the remote Pacific between 12˚N and the Gulf of Alaska and explored the remote Arctic up to 85˚N above Alaska. No Global Hawk had previously operated north of 70˚N.

Highlights of the Global Hawk flights include sampling a large fragment of the Arctic polar vortex in the Gulf of Alaska, sampling aerosol dust plumes from Asia extending from the surface to 10-km altitude over the Pacific, and extensive flight legs along the ground track of the A-Train satellites coinciding with satellite overpass times. The success of GloPac has provided a wealth of information and experience for science and operation teams that will increase the likelihood of success in future Global Hawk missions.

Dr. Paul A. Newman was the co-project scientist of GloPac. GSFC flew two instruments on the Global Hawk for GloPac: the Airborne Compact Atmospheric Mapper (PI: Dr. Scott Janz) and the Cloud Physics Lidar (PI: Dr. Matt McGill). Drs. Randy Kawa, Peter Colarco, Huisheng Bian, and Leslie Lait provided in-field flight planning support, while GMAO personnel (Drs. Arlindo DaSilva, Steven Pawson) provided forecast products for the mission.

Operation IceBridge

NASA's Operation IceBridge—a six-year mission of annual flights over the Arctic and Antarctic—is the largest airborne survey ever flown of polar ice. In 2010, the mission wrapped up its second year with two successful campaigns, one over the Arctic, and one over the Antarctic.

Arctic 2010

Dates: March 22-May 28, 2010

Flights: 28

Total miles flown: 62,842

Aircraft: DC-8 and P-3B

Instruments: Airborne Topographic Mapper, Laser Vegetation Imaging Sensor, Multichannel Coherent Radar Depth Sounder, Snow Radar, Ku-Band Radar Altimeter, Gravimeter, Digital Mapping Sensor

Campaign highlights:

After payload shakedown and checkout flights, the DC-8 transited on March 22, 2010, from NASA's Dryden Flight Research Center in Palmdale, CA, to Thule Air Base in Greenland. Here, the DC-8 flew flights over land and sea ice targets including a high-priority mission from Thule to Fairbanks. That flight was designed to cross the entire Arctic Ocean—from Greenland to Canada to Alaska—and map the varieties of sea ice. This mission provided a detailed snapshot of sea ice conditions over a large area of the Arctic, which can be compared with measurements collected during the Arctic 2009 campaign.

After completing 16 science flights from Thule, the DC-8 transited back to Wallops Flight Facility, where crew offloaded science instruments for the upcoming installation on the P-3B.

On May 5, 2010, the P-3B transited from Wallops Flight Facility to Greenland, where it flew the remaining science flights. This half of the campaign was based from Kangerlussuaq starting on May 5 and Thule starting on May 17, 2010. The transit back to Wallops Flight Facility on May 28, 2010, concluded the Arctic 2010 IceBridge deployment.

Antarctic 2010

Dates: Oct. 19 – Nov. 22, 2010

Distance flown: 40,098 nautical miles

Aircraft: DC-8

Instruments: Airborne Topographic Mapper, Laser Vegetation Imaging Sensor, Multichannel Coherent Radar Depth Sounder, Snow Radar, Ku-Band Radar Altimeter, Gravimeter, Digital Mapping Sensor

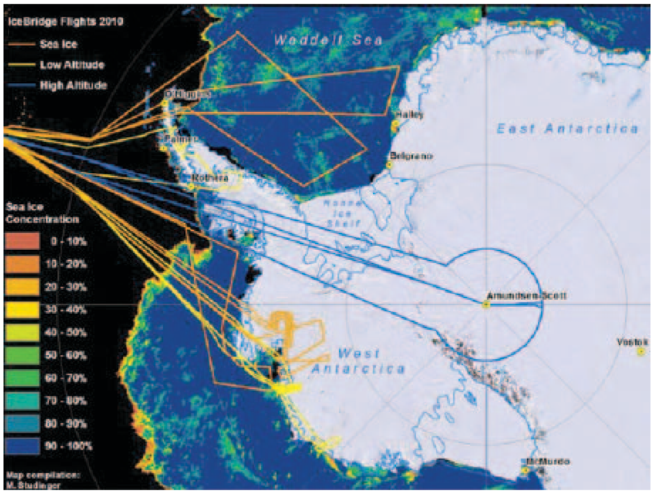


Figure 9.5. Antarctic 2010 flight paths

Campaign highlights:

On Oct. 19, 2010, the DC-8 transited from Santiago to Punta Arenas, Chile, where the remainder of the mission was based.

Inclement weather combined with aircraft downtimes slowed deployment progress, but adaptations of original plans led to 10 successful missions and use of 84 percent of the allocated science flight hours. IceBridge teams spent 115 hours in the air collecting data and flew 40,098 nautical miles, almost twice around the Earth.

Teams collected landmark sea ice data sets in the Weddell, Bellingshausen, and Amundsen Seas. Also over sea ice, IceBridge underflew ESA's CryoSat-2 satellite, allowing for the calibration and validation of satellite measurements.

Over land ice, IceBridge flights retraced every ICESat orbit ever flown by completing an arc at 86°S, the inflection point of all ICESat orbits around the South Pole. Teams surveyed glaciers along the Antarctic Peninsula, the Pine Island Glacier area, and in Marie Byrd Land.

Meetings and Milestones

A key component of the campaigns was the detailed flight plans developed well in advance of deployment. For the spring Arctic 2010 campaign, an ad-hoc science working group convened for two days in January at GSFC to identify targets for land ice and sea ice. Informal discussions continued over subsequent months to solidify and prioritize the science targets.

In March 2010, a ROSES solicitation was issued to competitively select members of the IceBridge science team who would handle such matters in the future. A second ROSES solicitation was issued to competitively select the instruments that would comprise the IceBridge instrumentation suite for the next three years of IceBridge operations.

A second ad-hoc meeting was held in late June 2010 in Seattle, WA, to begin flight planning for the 2010 Antarctic campaign. Both sea ice and land ice targets were discussed, as well as a one-day workshop on ice penetrating radar data collection, processing, and distribution. Flight planning continued to mature over the subsequent months.

The instrument suite PIs and science team PI selections were formally announced in August 2010. The first formal IceBridge science team meeting was held at GSFC shortly thereafter in September 2010. The primary work of the science team in 2010 was to review existing science priorities and flight plans, and develop the Level 1 science requirements, and mission success criteria, that will guide the IceBridge mission in the coming years.

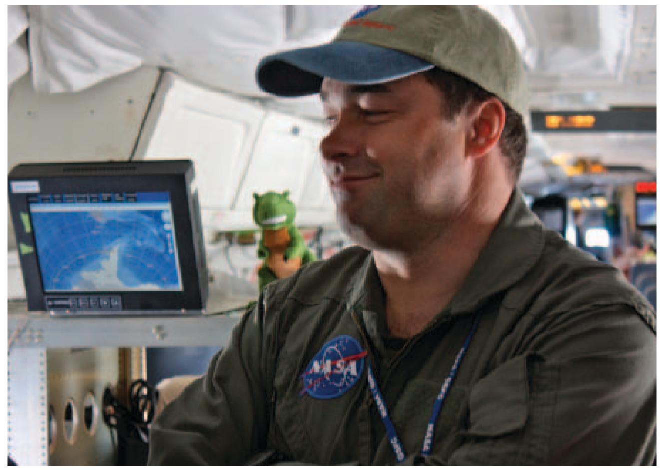


Figure 9.6. IceBridge project scientist Michael Studinger, of NASA's Goddard Space Flight Center/UMBC, works onboard the DC-8 during a flight during the 2010 Antarctic campaign of Operation IceBridge. Credit: NASA/ Kathryn Hansen

9.5 Missions in Development

Glory

As this report was being finalized, the Glory Mission failed to achieve orbit and was lost. This failure, plus the very recent elimination of CLARREO from the President's FY 2012 budget is now causing us to re-assess our planning for near-future Earth radiation missions.

The NASA Glory mission is a remote-sensing Earth-orbiting observatory designed to support the U.S. Climate Change Science Program. It is scheduled for launch on February 23, 2011, as part of the A-Train constellation of Earth-orbiting satellites. Glory is intended to meet the following four scientific objectives:

- Improve the quantification of the effect of solar variability on the Earth's climate by continuing the uninterrupted 32-year satellite measurement record of Total Solar Irradiance (TSI).
- Facilitate the quantification of the aerosol direct and indirect effects on climate by determining the global distribution of the optical thickness and microphysical properties of natural and

anthropogenic aerosols and clouds with much improved accuracy.

- Provide better aerosol representations for use in various remote-sensing retrievals and model parameterizations, thereby allowing improvements in aerosol assessments by other operational satellite instruments and modeling efforts.
- Provide an improved framework for the formulation of future comprehensive satellite missions for aerosol, cloud, and ocean color research.

These science objectives will be met by implementing two independent instruments. The Total Irradiance Monitor (TIM) will monitor sunlight incident on the Earth's atmosphere by performing measurements of TSI with extremely high accuracy and precision. The Aerosol Polarimetry Sensor (APS) will have the ability to collect accurate multi-angle photopolarimetric measurements of the Earth along the satellite ground track over a broad visible and near-infrared spectral range, thereby providing aerosol retrievals to levels of precision and accuracy heretofore unachievable.

The Glory mission is managed by GSFC, and the project science office is led within ESD from GISS. The APS instrument team is also located at GISS, while the TIM team is at LASP in Colorado. Several other ESD scientists are members of the Glory Science team and will also be involved with calibration/validation efforts post-launch.

Figure 9.7. The Glory spacecraft is shown inside its fairing during preparations for launch from VAFB on February 23, 2011.

Aquarius/SAC-D

Aquarius is a microwave instrument designed to map the salinity field at the ocean surface from space. It is the primary instrument on the Aquarius/SAC-D mission, a partnership between NASA and the Argentine space agency (CONAE). The science objective of Aquarius is to monitor the seasonal and interannual variation of the large-scale features of the surface salinity field in the open ocean by providing salinity maps on a monthly basis with a spatial resolution of 150 km and an accuracy of 0.2 psu. These data will promote understanding of ocean circulation and its role in the global water cycle and climate. The Aquarius/SAC-D observatory is scheduled for launch in June 2011.

The goal of the Aquarius instrument is to provide global maps of the sea surface salinity field in the open ocean on a monthly basis with an average accuracy of 0.2 psu and at a spatial resolution of 150 km. These are requirements derived from the need to better understand the buoyancy-driven thermohaline circulation of the ocean and its relationship to climate and the global water cycle [1]. Aquarius will map the global ice-free ocean every 7 days from which monthly average composites will be derived. This will provide a snapshot of the mean field, as well as resolve the seasonal to interannual variations over the three-year baseline of the mission.

Aquarius is the primary instrument on the Aquarius/SAC-D mission. The mission is composed of two parts: (a) Aquarius, a radiometer/scatterometer instrument combination for measuring sea surface salinity, which is being developed as part of NASA's Earth System Science Pathfinder (ESSP) program; and (b) SAC-D, which is the fourth spacecraft service platform in the CONAE Satelite de Aplicaciones Cientificas (SAC) program and includes several additional instruments. Table 9.1 lists the instruments that are part of this observatory. This is a truly international partnership with instruments provided by the space agencies of Argentina, Canada, France, Italy, and the United States. In addition, the observatory was assembled in Argentina, tested in Brazil (at the Brazilian Space Agency facility, INPE/LIT in Sao Jose dos Campos), and will be launched from Vandenberg Air Force Base in the United States.

The primary instrument for measuring salinity is the L-band (1.4 GHz) radiometer. Aquarius consists of three separate radiometers that image in pushbroom fashion with the three antenna beams looking across track. The antenna is a 2.5-m diameter, offset parabolic reflector with three feed horns, and the three beams are arranged to image with the boresight aligned to look across track, roughly perpendicular to the spacecraft heading and pointing away from the sun. The three beams point at angles of θ = 25.8, 33.8, and 40.3 degrees with respect to the spacecraft nadir with resolution of approximately

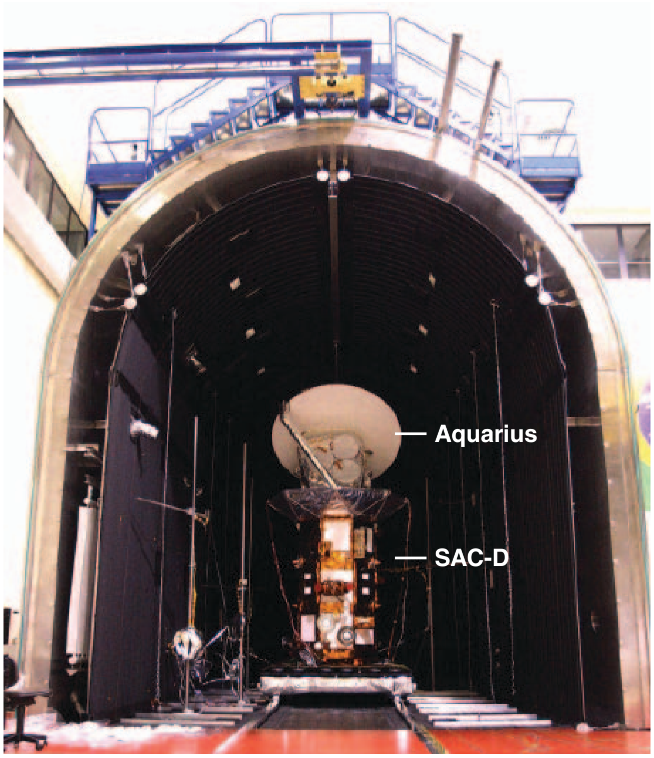


Figure 9.8. Aquarius/SAC-D being installed in the Thermal Vacuum chamber.

90 km (inner beam) to 150 km (outer beam). Together the three beams cover a swath of about 390 km. More information about the hardware can be found in [2] and additional details about the science objectives are in [1]. Mapping sea surface salinity is a challenging measurement and to do this Aquarius has several unique features. Most notable are the inclusion of the scatterometer viewing the same spot as the radiometer to provide a correction for roughness, a polarimetric radiometer channel (third Stokes parameter) to help correct for Faraday rotation, and tight thermal control and internal calibration of the radiometers.

The Aquarius/SAC-D observatory is currently completing environmental testing at the test facility of the Brazilian space agency, INPE/LIT, in Sao Jose dos Campos, Brazil. It has completed EMI/EMC and thermal vacuum testing. The observatory will be transported to Vandenberg AFB in March and launch is scheduled for June 9, 2011. Figure 9.8 shows the observatory being installed in the thermal vacuum chamber at INPE/LIT. Aquarius comprises the top third of the observatory. It begins with the dish-like sun shield which is part of the thermal control design. The large reflector can be seen at the top in its stowed configuration. The three feed horns are visible between the sun shield and the reflector. The large bar descending from left to right is the support arm which holds the reflector in its deployed configuration. SAC-D is the gold colored cylinder between the sun shield (silver) and the support platform. In this view looking at the top of the observatory, the GPS antennas are visible at the base of the observatory and star trackers can be seen toward the middle.

Table 9.1. Aquarius/SAC-D Instruments.

Instrument	Objective	Description	Resolution	Source
Aquarius	Sea surface salinity (SSS)	Radiometer (1.4 GHz) Radar (1.26 GHz)	76 x 94 km 84 x 120 km 96 x 156 km	NASA
MWR: Microwave Radiometer	Precipitation; wind speed; sea ice	23.8 and 37 GHz 390 km swath	40 km	CONAE
NIRST: New Infrared Sensor Technology	Fires, sea surface temperature	3.8, 10.7, 11.7 μm 180 km swath	350 m	CONAE
HSC: High Sensitivity Camera	Urban lights, fire detection	450–900 μm 700 km swath	200–300 m	CONAE
DCS: Data Collection System	Environmental data collection	401.55 MHz uplink	2 contact/day 200 platforms	CONAE
ROSA: Radio Occulation Sounder for Atmosphere	Atmospheric temp & humidity profiles	GPS occultation	300 km	ASI (Italy)
CARMEN 1: ICARE & SODAD	Effects of radiation, space μ-particles, & debris	Si/LI detectors NS SMOS sensors		CNES (France)

References:

[1] G.S.E Lagerloef, R. Colomb, D. Le Vine, F. Wentz, S. Yueh, C. Ruf, J. Lilly, J. Gunn, Y. Chao, A. deCharon and C. Swift, The Aquarius/SAC-D mission – Designed to Meet the Salinity Remote Sensing Challenge, *Oceanography Magazine*, Vol 21 (no 1), pp 68-81, March 2008.

[2] D.M. Le Vine, G.S.E. Lagerloef, F. R. Colomb, S. H. Yueh, F. A. Pellerano, Aquarius: An Instrument to Monitor Sea Surface Salinity from Space, *IEEE Trans. Geosci. Remote Sens.*, Vol. 45, no. 7, pp. 2040-2050, July 2007.

GPM

Global Precipitation Measurement (GPM) is an international satellite mission designed to provide next-generation precipitation observations every two to four hours anywhere in the world. The GPM concept centers on the deployment of a Core Observatory that will carry an advanced radar/radiometer system consisting of a Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI). Together these instruments will establish a new reference standard for precipitation remote sensing that can be used to unify and refine precipitation estimates from a constellation of research and operational satellites.

GPM is a joint venture between NASA and JAXA. The GPM Core Observatory is scheduled to launch in mid-2013. Domestic and international space agencies will provide additional satellites in the GPM constellation in partnership with NASA and JAXA. NASA also plans to provide a second GMI on a partner-provided GPM Low-Inclination Observatory that will launch in late 2014.

GPM is a science discovery mission with integrated application goals. GPM measurements will provide new insights into precipitation microphysics and advance understanding of global water cycle variability. Also, by providing data in near real-time, GPM will directly benefit society by extending current capabilities in numerical weather prediction, as well as the monitoring and forecasting of natural hazard events such as hurricanes, floods, and landslides.

Scientists in the Laboratory for Atmospheres have played a crucial role in GPM with over 40 Laboratory scientists participating in GPM activities. Contributions included: developing definitions of the science and instrument requirements of the mission, developing algorithms to retrieve precipitation information from active and passive microwave sensor measurements, conducting targeted field campaigns to support pre-launch algorithm development, and employing satellite precipitation data in scientific research and societal applications.

Figure 9.9. The GPM constellation of satellites with the GPM Core Observatory shown at the upper right.

LDCM

The Landsat Data Continuity Mission (LDCM) is the successor mission to Landsat 7. Landsat satellites have continuously acquired multispectral images of the global land surface since the launch of Landsat 1 in 1972. The Landsat data archive constitutes the longest moderate-resolution record of the global land surface as viewed from space. The LDCM mission objective is to extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and man-made causes of change can be detected and differentiated.

The LDCM is the eighth satellite in the Landsat series. The development of LDCM is a partnership between NASA and the U.S. Geological Survey (USGS). GSFC is responsible for the development of the overall mission. USGS is responsible for ground system development and will operate LDCM after launch. The LDCM satellite is being developed by Orbital Sciences Corporation and will accommodate two instruments, the Operational Land Imager (OLI) built by Ball Aerospace and Technologies Corporation and the Thermal InfraRed Sensor (TIRS) built by GSFC. The Kennedy Space Center is responsible for the Atlas V launch vehicle. The USGS Earth Resources Observation and Science (EROS) Center will receive, archive, and distribute LDCM data.

Both the OLI and TIRS represent an evolutionary advancement in technology relative to previous Landsat sensors. All of the earlier Landsat satellites carried optical-mechanical scanners that used oscillating mirrors to sweep the cross-track field-of-view across the orbital ground paths. The LDCM sensors will both use long arrays of detectors aligned across the focal planes to view the cross-track swath. The major advantage of the long detector arrays is a substantial improvement in signal-to-noise-ratio performance leading to improved capabilities

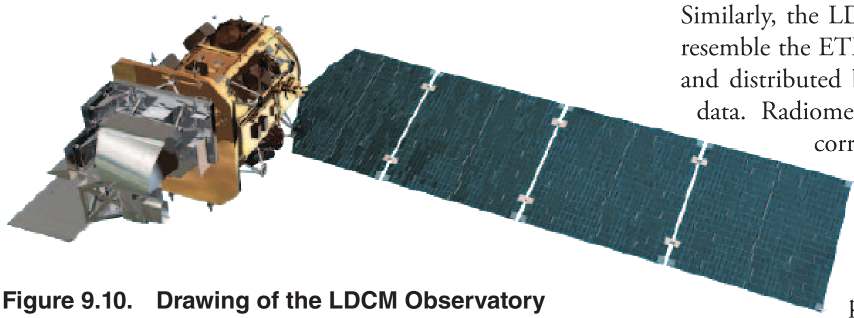


Figure 9.10. Drawing of the LDCM Observatory (courtesy Orbital Sciences Corporation).

for characterizing land cover and detecting change over time. The design also presents challenges to achieving uniformity in radiometric and spectral response and to calibration across the long detector arrays. The Advanced Land Imager (ALI) flown aboard the Earth Observing-1 (EO-1) spacecraft demonstrated the potential and challenges of this technical approach for remote imaging.

OLI will acquire data for eight visible, near-infrared, short-wave infrared spectral bands with a spatial resolution of 30 m and one panchromatic band with a resolution of 30 m. Seven of the bands are comparable to seven bands sensed by the Enhanced Thematic Mapper-Plus (ETM+) aboard Landsat 7. Two new bands are added to OLI: one blue band for sensing coastal water color and atmospheric aerosol attenuation and one shortwave infrared band for sensing the presence or absence of cirrus clouds.

TIRS will collect data for two thermal infrared bands with a spatial resolution of 100 m. In comparison, the Thematic Mapper (TM) sensors on Landsat 4 and Landsat 5 collect data for one thermal band with a spatial resolution of 120 m while the Landsat 7 ETM+ collects data for one thermal band with a resolution of 60 m. The two TIRS thermal bands will facilitate atmospheric correction of the thermal data leading to more accurate retrievals of surface temperature.

The fundamental LDCM operations concept is to collect, archive, process, and distribute science data in a manner consistent with the collection, archiving, processing, and distribution of science data from the Landsat 7 mission. To that end, the LDCM observatory will operate in a 716 km near-circular, near-polar, sun-synchronous orbit. The observatory will have a 16-day ground track repeat cycle with an equatorial crossing at 10:00 a.m. (+/- 15 minutes) mean local time during the descending node of each orbit. In this orbit, the LDCM observatory will follow a sequence of fixed ground tracks (also known as paths) defined by the second Worldwide Reference System (WRS-2). WRS-2 is a path/row coordinate system used to catalog the image data acquired from the Landsat 4, 5, and 7 satellites. These three satellites have all followed the WRS-2 paths and all of the science data are referenced to this coordinate system. The LDCM science data will likewise be referenced to the WRS-2.

Similarly, the LDCM will produce data products that closely resemble the ETM+ Level 1 data products currently produced and distributed by the USGS at no cost to those requesting data. Radiometrically corrected, co-registered, and terrain corrected OLI and TIRS data will be merged to create a single integrated Level-1 data product known as a Level 1T scene. The data will be resampled to provide 30 m pixels (with the exception of 15 m pixels for the panchromatic band, oriented north-up, and registered to the Universal Transverse Mercator (UTM) cartographic projection. USGS will retain the no-cost data distribution policy for LDCM data and this relatively new policy, implemented in October 2008, has resulted in an explosion of Landsat data use.

More information can be found on the internet at the following URL: http://ldcm.gsfc.nasa.gov/.

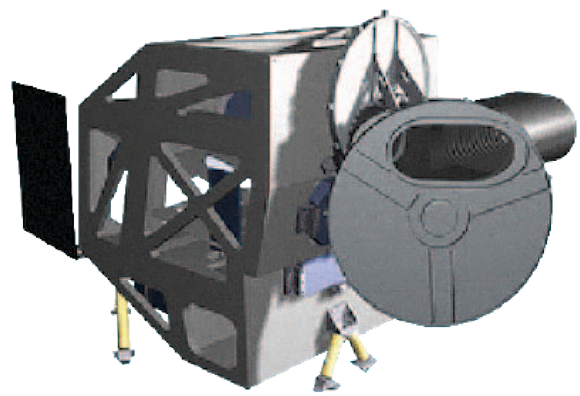


Figure 9.11. Drawing of the Operational Land Imager (OLI) (courtesy Ball Aerospace Technology Corporation).

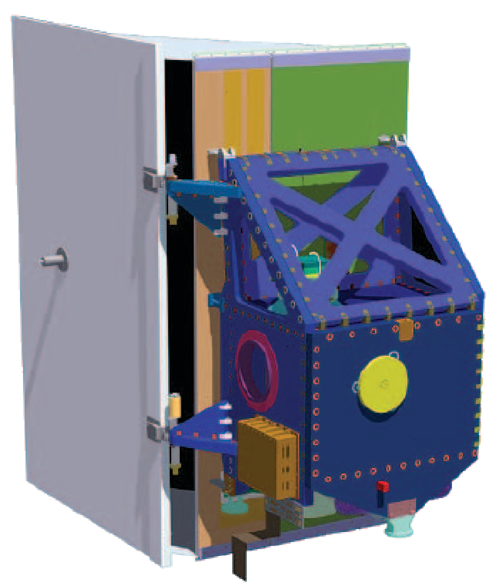


Figure 9.12 Drawing of the Thermal Infrared Sensor.

NPP

NASA's Goddard Space Flight Center manages the NPOESS Preparatory Project (NPP) climate and weather satellite mission. Dr. James Gleason is the NPP Project Scientist. International partners include the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and JAXA. The NPP satellite was a pre-cursor mission to the National Polar-orbiting Operational Environmental Satellite System (NPOESS) that has recently been restructured under the Joint Polar Satellite System (JPSS) Program. (See Future Missions for more information on JPSS.)

Data from the NPP mission will provide a continuation of the EOS record of climate-quality observations after EOS Terra, Aqua, and Aura (i.e., it will extend key Earth system data records and/or climate data records of equal or better quality and uncertainty in comparison to those of the Terra, Aqua, and Aura sensors). The NPP instrument suite will collect and distribute remotely sensed land, ocean, and atmospheric data to the meteorological and global climate change communities. It will provide atmospheric and sea surface temperatures, humidity sounding, land and ocean biological productivity, cloud and aerosol properties, and total/profile ozone measurements.

NPP instruments include the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite (OMPS), the Cloud and Earth Radiant Energy System (CERES), and the Visible Infrared Imaging Radiometer Suite (VIIRS). Ball Aerospace and Technologies Corporation, Boulder, CO, built the NPP spacecraft and is performing the integration and checkout of the NPP satellite. The polar-orbiting satellite is scheduled to launch October 25, 2011.

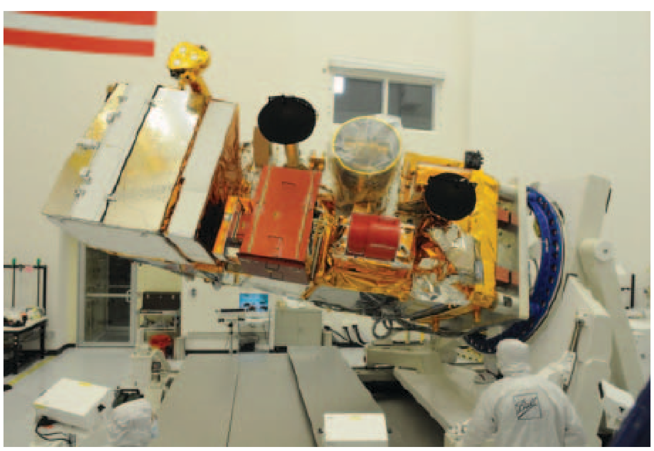


Figure 9.13. NASA's NPP weather satellite shown in a Ball Aerospace clean room where the instruments have be integrated and the spacecraft is now preparing for environmental testing prior to its October 2011 launch. Credit: Ball Aerospace

Tier 1 NRC Decadal Survey Missions

Missions in development include the NRC Decadal Survey missions which refer to the 15 mission portfolio recommended by the NRC in 2006. NRC Decadal Survey missions are separated into three time frames or tiers. Tier 1 missions are all in formulation and will launch between 2015 and 2019. These missions include the SMAP mission led by JPL with GSFC providing the key radiometer system, the ICESat II mission led by GSFC, the CLARREO mission led by the Langley Research Center with GSFC providing the Reflected Solar instrument, and the DESDynI mission led by JPL with GSFC as the lead for the Lidar platform.

ICESat II

In December 2009, the ICESat II mission passed Key Decision Point A (KDP-A) and since then has been in Phase A. Several open items in the measurement and instrument concept were closed during 2010 and the instrument concept as well as measurement (Level 2) and instrument (Level 3) requirements have become stable. The project, in close collaboration with the ICESat-2 Science Definition Team, has now developed a design that should meet the Level 1 baseline science requirements. The measurement concept is illustrated in Figure 9.14.

The sampling pattern of ICESat II consists of three pairs of beams. The spacing within each pair is 90 m; this spacing will allow us to determine ice sheet surface slope on an orbit-by-orbit basis (and address a key limitation of ICESat). A value of 90 m was chosen based on the correlation length scale of ice sheet surface slopes. If the spacing is greater than about 100m, we cannot reliably interpolate to find the surface slope. The cross-track distance of about 3 km between the pairs was chosen to optimize spatial coverage. Each pair consists of a low-energy and a high-energy beam indicated by the different shades of green in Figure 9.14. While the low energy beam is sufficient for high-reflectivity ice sheet targets (and thus slope determination), the high-energy beams are needed to get sufficient returns from low reflectivity leads in sea ice and to penetrate forested areas. The left side of Figure 9.14 shows a representation of the beam pattern. All six beams measure surface topography simultaneously; the instantaneous sampling pattern is shown on the right side of Figure 9.14. The 90 m separation between the high- and low-energy beams is achieved by slightly yawing the spacecraft. This strategy enables us to potentially modify the spacing of the beams to be greater than or less than 90m by varying the yaw angle of the spacecraft.

Other open trades in the measurement strategy were also closed in 2010. The project, again in close collaboration with the Science Definition Team, settled on a pulse repetition frequency of 10 kHz and on a nominal 500-km altitude orbit. All trades were analyzed in collaboration with the instrument team to develop measurement requirements, such as geolocation knowledge and pointing precision.

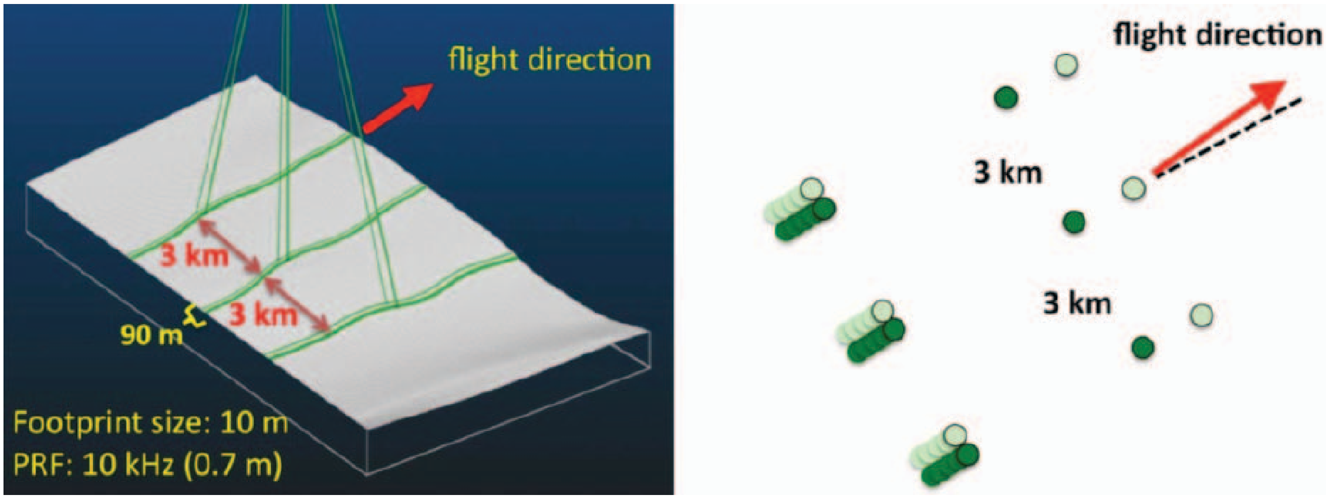


Figure 9.14. Surface geometry (left) and beam pattern (right) of the ICESat II measurement concept.

Photon-counting data were collected by low-flying aircraft in vegetated areas in Maryland and New Jersey using an instrument developed by Sigma Space in late 2009. These data, as well as data collected over Greenland in summer 2009, were processed and sub-sampled to simulate ICESat II data. These data were analyzed to assess potential performance over ice sheets and vegetated targets, begin algorithm development, and estimate ranging errors over those areas.

In November 2010, the ICESat II airborne simulator (MABEL) developed by Instrument Scientist Dr. Matt McGill, had its first flight out of NASA Dryden Flight Research Center. The design, development, and fabrication of this instrument were a major effort in 2010. The instrument performed extremely well and collected data in five back-to-back flights over forested areas, snow covered targets in the Rocky Mountains, salt flats in Utah, and the open ocean. Those data are currently being calibrated and geolocated and will be made available to the Science Definition Team and the science community in February 2011.

Significant work was also put into performance modeling through development of design cases (typical surface and atmosphere conditions for which ICESat II needs to take measurements) and the results were used to develop and quantify the requirements flowdown from the baseline Level 1 Requirements to the Level 2 Mission Requirements and Level 3 Instrument Requirements. In close collaboartion with the other components of the ICESat II project, this work has prepared us for our mission System Requirements Review, scheduled for March 2011.

SMAP

The Soil Moisture Active Passive (SMAP) mission is one of the first Earth observation satellites being formulated by NASA in response to the NRC Decadal Survey. Scheduled to launch in late 2014, SMAP will provide high resolution and frequent revisit global mapping of soil moisture and freeze/thaw state. These observations will (1) improve our understanding of linkages between the Earth's water, energy, and carbon cycles; (2) provide economic and societal benefits in many application areas including numerical weather and climate prediction, flood and drought monitoring, agricultural productivity, human health, and national security; (3) help to address priority questions on climate change; and (4) potentially provide continuity with brightness temperature and soil moisture measurements from ESA's Soil Moisture Ocean Salinity and NASA's Aquarius missions.

The SMAP mission concept will utilize an L-band radar and radiometer sharing a single rotating 6-meter mesh reflector

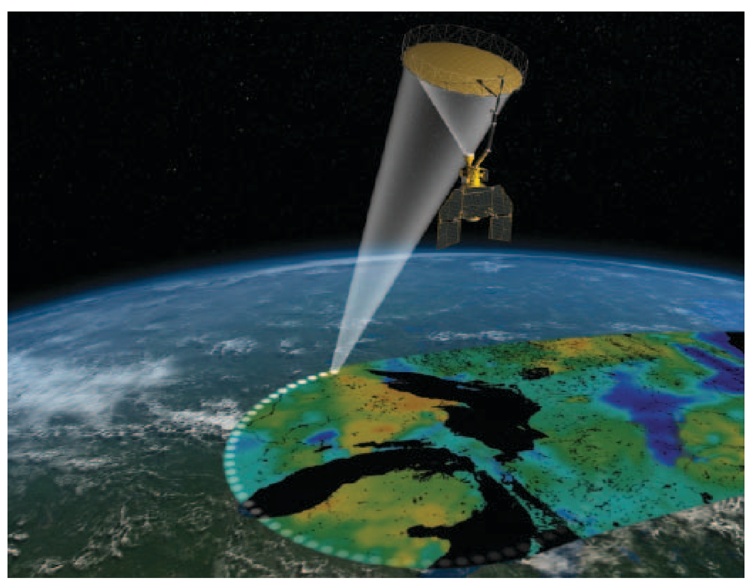


Figure 9.15. The SMAP mission concept consists of an L-band radar and radiometer sharing a single spinning 6-m mesh antenna in a sun-synchronous dawn/dusk orbit.

antenna. The mission will fly in a 680 km sun-synchronous dawn/dusk orbit with an 8-day repeating ground track aboard a 3-axis stabilized spacecraft (Figure 9.15). These instruments will provide high-resolution and high-accuracy global maps of soil moisture at 10 km resolution and freeze/thaw at 3 km resolution every two to three days. In addition, SMAP will use these surface observations with advanced modeling and data assimilation approaches to provide estimates of deeper root-zone soil moisture and net ecosystem exchange of carbon [2].

SMAP is being managed by JPL, with contributions from GSFC. SMAP completed its Phase A Mission Concept Study for NASA and transitioned into Phase B (Formulation and Preliminary Design) in February 2010. The project completed preliminary designs for the observatory and held successful preliminary design reviews (PDRs) for the instrument and spacecraft systems in November and December 2010, respectively, in preparation for the mission-level PDR in 2011. Work is now underway building engineering models of the instrument and mission-unique spacecraft assemblies. NASA Headquarters is currently in the process of selecting launch services for SMAP, and the project expects to conduct its mission PDR and transition into Phase C shortly after the launch service selection process is completed.

The radiometer instrument is being provided to the SMAP Project by GSFC, and three major trade studies were concluded in 2010: (1) 1553 Command and Telemetry Interface from RS-422—the radiometer adopted the Integrated Control Electronics 1553 command interface to limit the number of slip rings to the spun side of the spacecraft; (2) Active Thermal Control—the cold-biased passive radiometer design will be supplemented with active proportionally controlled heaters to provide increased thermal stability margin while also allowing for thermally induced gain non-linearity risk mitigation; (3) RF Systems —packaging (microstrip, stripline, coaxial), switch design, stackup, gain non-linearity mitigation, radiometric, and RF performance were finalized. In preparation for the radiometer PDR, the grounding architecture was reviewed and base-lined along with Engineering Peer Reviews for the Radiometer Front End, Radiometer Back End, Inheritance (Coupler and Correlated Noise Source), Radiometer Digital Electronics and Digital Signal Processing, Integration and Test, Calibration, and Algorithms. The radiometer passed all Subsystem and Instrument Level PDRs and is now beginning work on the Engineering Test Unit.

The SMAP Project has established four community working groups as a means to enable broad science participation in the SMAP mission (Algorithms, Calibration/Validation, Applications, and Radio-Frequency Interference). The working groups are led by Science Definition Team (SDT) members and provide forums for information exchange on issues related to SMAP science and applications goals and objectives. SMAP also has international SDT members who provide direct links to activities that support SMAP science and applications outside the USA. For example, two airborne field campaigns—one in Canada and another in Australia— have been conducted in support of testing SMAP algorithms in 2010. During the past year, the SMAP Project has prepared preliminary Algorithm Theoretical Basis Documents for each mission science product, established a prototype algorithm testbed at JPL to enable testing and evaluation of the performance of candidate algorithms, conducted a community workshop and peer review on science algorithms, worked with NASA Headquarters to release a "Dear Colleague Letter" soliciting SMAP calibration/validation sites worldwide, and developed an Applications Plan that describes the project's planned outreach to potential applications users and early adopters.

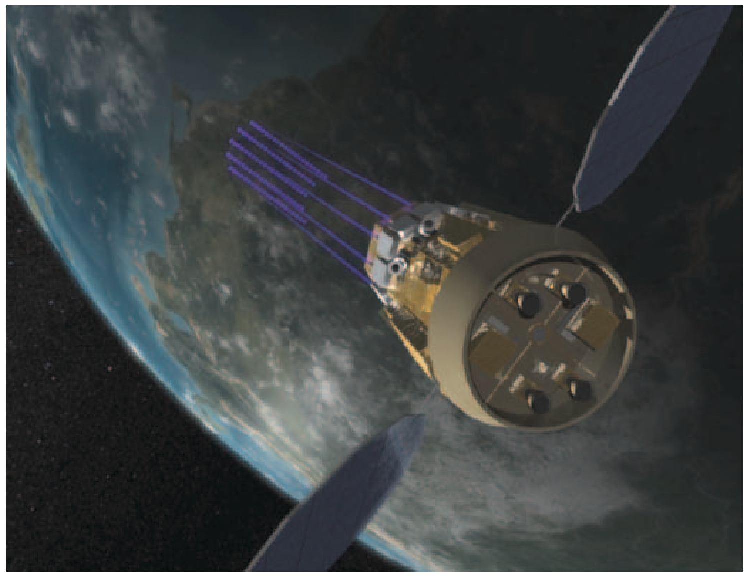


Fig. 9.16. The DESDynI lidar will have five laser beams with a surface resolution of 25 m and 30 m footprint spacing providing necessary coverage of the Earth's forested and ice covered areas to meet science requirements.

References:

[1] National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* pp. 400, 2007.

[2] Entekhabi, D., E, Njoku, P. O'Neill, K. Kellogg, plus 19 others, The Soil Moisture Active Passive (SMAP) Mission, *Proceedings of the IEEE*, Vol. 98, No. 5, May, 2010.

DESDynI

As this report was being finalized, the President's FY 2012 budget was released, and with it, the ecosystem, DESDynI-Lidar portion of the DESDynI Mission was eliminated. Our ecosystem scientists are now preparing alternative plans that will achieve a major portion of the DESDynI-Lidar scientific goals.

The Deformation, Ecosystem Structure, Dynamics of Ice (DESDynI) mission will study the Earth's forested ecosystems, ice sheets and glaciers, and areas prone to volcanoes and earthquakes. Two complementary technologies will be utilized to make these measurements, Multi-Beam Lidar, and L-Band Synthetic Aperture Radar (SAR).

The mission will launch the lidar and radar as separate platforms beginning as early as October 2017. The emphasis of the SAR is solid earth and cryosphere, whereas the lidar will focus on ecosystem structure and also make ice sheet and glacier surface elevation measurements. A complete set of ecosystem structure measurements requires Lidar waveforms and polarimetric SAR. The fusion of these types of data will be important to provide accurate and higher resolution data products.

GSFC will provide the lidar spacecraft for the DESDynI mission. Figure 9.16 depicts the lidar with its 5 lasers acquiring 25 m lidar footprints nearly contiguously as the satellite orbits from about 370 km above the Earth. The mission has a nominal observation period of two years.

CLARREO

The very recent elimination of CLARREO from the President's FY 2012 budget, plus the failure of the Glory Mission to achieve orbit, is causing us to re-assess our planning for near-future Earth radiation missions.

The Reflected Solar Spectrometer for the Climate Absolute Radiance and Refractivity Observatory (CLARREO) will obtain the solar spectral reflectance of the Earth and its atmosphere relative to the solar irradiance spectrum. The spectral resolution of the sensor has been chosen to resolve atmospheric structure, composition, clouds, surface properties, and spectral bands of sensors that will be intercalibrated by the RSS. Reflectance measurements will have an absolute uncertainty of 0.3% at k=2 confidence in order to achieve the detection of decadal change necessary to reduce uncertainties in cloud feedback, surface albedo feedback, and land use change radiative forcing.

The RSS instrument concept currently revolves around a two spectrometer approach. A blue spectrometer will rely on a silicon-based detector to cover the 320 to 640 nm spectral range and a red/NIR spectrometer will cover the 600 to 2300 nm spectral range using a HgCdTe detector. The original proposed design presented at an internal Peer-MCR in January 2010 was a three-spectrometer approach in which the red/NIR was two separate spectrometers. That design offered the lowest overall risk with simpler design, fabrication, build, and test/calibration. The two-spectrometer approach resulted from a study in April 2010 to reduce the mass of the overall RSS, allowing it to fly on a dedicated platform while providing maximum flexibility in launch vehicle selection.

The need for reduced mass occurred as part of CLARREO reformulating its mission in response to the schedule guidance and budget profile that was released in early 2010. The schedule guidance stipulated that CLARREO shall be comprised of two launch opportunities, rather than the February 2010 mission architecture in which two observatories would have been launched in late 2016/ early 2017 with each observatory carrying all instruments. In response to the new schedule and budget guidance, the CLARREO team examined concepts that provide the most science within the schedule and budget constraints.

The two-spectrometer approach was that presented during the successful Project MCR held on November 17, 2010. The mission proposed during MCR consists of two IR/GNSS-RO platforms launched in 2018 and two RS platforms launched in 2020. The rationale for the RS launch in 2020 was in part decided during a July Science Team Meeting that demonstrated the RS science maturity had made progress relative to IR but still lacked peer-reviewed publications. Also, the RS on-orbit calibration traceability verification is more challenging/higher risk than the IR. The MCR resulted in three RFAs and six concerns (one related to the maturity of the RSS calibratability, highlighting the risk that design changes may be needed to achieve the accuracy requirements).

A good portion of the progress demonstrated at the Science Team meeting resulted from efforts at GSFC on a high-fidelity breadboard to demonstrate the ability to determine reflectance of a scene by taking the ratio of the solar irradiance and the signal from the scene. The measurement approach benefits from the breadboard:

1. Demonstrating the feasibility of attenuation methods: perforated plate, pinhole plate, neutral density filters.
2. Developing and checking calibration protocols and methods including a path to SI traceability (source and detector standards).
3. Demonstrating the ability to design and produce optics with minimal stray light.
4. Demonstrating the ability to minimize polarization sensitivities.
5. Evaluating detector technology.
6. Validating the ability to control thermal stability.

The plan developed for the breadboard starts with an optical package spanning both spectrometers (320-1150 nm) followed by one that simulates the Red/NIR spectrometer. Both breadboards will be portable, permitting validation of reflectance retrievals in the laboratory and field, including NIST-based measurements to evaluate calibration techniques and error budgets. Development of breadboard also allows field demonstration of a solar-based calibration including evaluation of absolute solar irradiance, lunar model verification, and data to support calibration of currently-flying sensors (MODIS, CERES, and Landsat).

RSS Breadboard progress at GSFC included the machining of rough optics by Code 547 including thermal cycling for stress relief, and supporting the training of technicians in Code 551 to enable optics fabrication using a new machine for figuring complex optics. The silicon detector has been hybridized (bump bonded) by Code 553 to a test ROIC wafer. 545 performed a thermal performance test of the detector cooling and control system. The HgCdTe detector development is underway with the vendor. Optical filters for depolarizing the incident energy as well as attenuating filters to permit direct solar view have been acquired for characterization. Another key aspect is that NIST will be delivering a SIRCUS calibration unit to the 551 OCL for CLARREO after tests at NIST on ORCA include CLARREO personnel participating for training purposes.

9.6 Future Missions

GSFC scientists, instrument engineers, and mission planners have provided considerable support to NRC Decadal Survey Tier II missions including the SWOT mission, the ASCENDS mission, the ACE mission, the HypsIRI, and the GEOCAPE mission. The Tier II missions are in pre-formulation and will be launched no earlier than 2019 beginning with SWOT and ASCENDS. Tier III missions will not launch before 2024+ and are described in Table A.2.

SWOT

The Surface Water Ocean Topography (SWOT) mission is an NRC Decadal Survey recommended Tier II satellite scheduled to launch in 2019. SWOT's principal sensor is the Ka-band Radar Interferometer (KaRIN) swath imager, complemented with an additional nadir altimeter. SWOT objectives are (1) to characterize mesoscale and submesoscale ocean processes; (2) to provide a global inventory of terrestrial surface water bodies and changes in global stored water; and (3) to estimate change in river discharge at sub-monthly to annual time scales.

Figure 9.17. Snake River test site.

There are currently three projects currently underway at GSFC directly in support of SWOT. They are (1) improved River Discharge Estimation Through Assimilation of SWOT Altimetry; (2) improved Coastal Modeling of the Interaction of Surface Hydrology and Estuary Dynamics, focusing on the Chesapeake Bay; and (3) improved understanding and modeling of the flooding region of a delta region, focusing on the Atchafalaya River in Southern Mississippi.

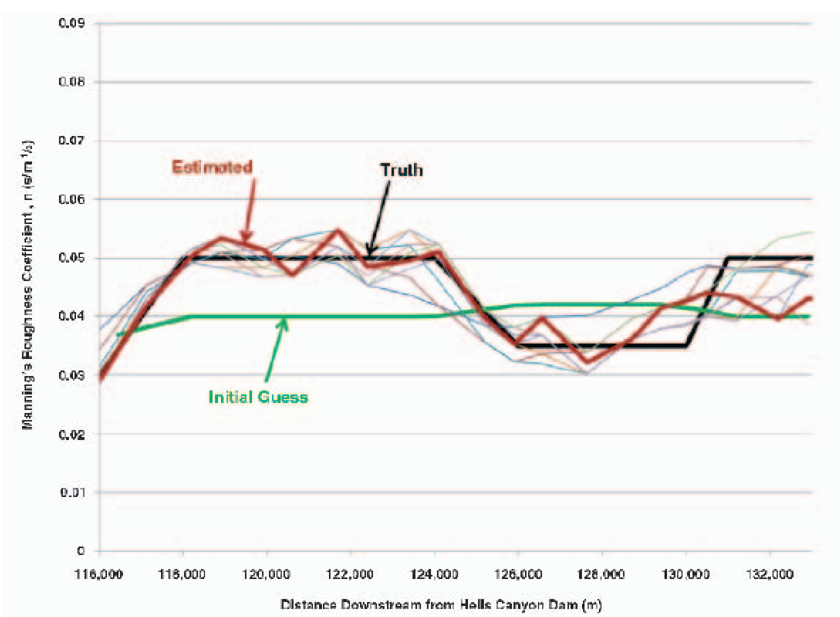
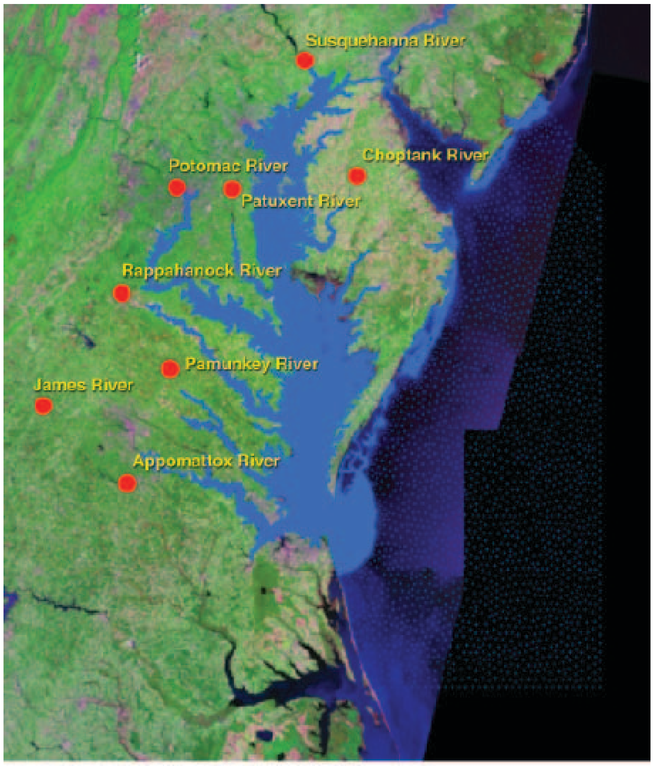


Figure 9.18. Estimated (red) and Truth (black) Manning's n for a 20km reach of the Snake River using Mike 11 and SWOT (After Jasinski et al, 2010).



Chesapeake Bay Principal Tributaries

Figure 9.19. Chesapeake Bay Estuary test site. Domain contains 248k nodes and 447k mesh elements.

GSFC hydrologists have been investigating mechanisms how SWOT altimetry will improve the accuracy of river discharge and flooding within the context of sophisticated hydrodynamics models. A first study focuses on improved short-term discharge forecasts through assimilation of SWOT altimetry. The study site is Snake River, Idaho, as shown in Figure 9.17. The model employed is MIKE11 by DHI, Inc. MIKE11 is perhaps the most theoretically sophisticated 1D hydrodynamics model available today, containing data assimilation algorithms including the Ensemble Kalman Filter (EnKF). Specific accomplishments during the past year include (1) calibration of MIKE11 to the Snake River, ID, with data support from USGS and Idaho Power; (2) development and testing of a data assimilation algorithm for improved updating and forecasting of stream discharge using the ensemble Kalman Filtering in conjunction with hypothetical SWOT altimetry; (3) determination of river discharge sampling requirements; and (4) development of an algorithm for improved estimation of the Manning's n roughness coefficient, shown in Figure 9.18. The above results were presented at the Altimetry of Oceans and Hydrology Meeting, Lisbon, October 2010.

A second project addresses improved hydrodynamic modeling of the Chesapeake Bay Estuary and other coastal regions. It focused on two areas: (1) observational sampling requirements for the Bay over a range of tidal conditions, and (2) the impact of tributary flow on bay hydrodynamics. Accomplishments during 2009-2010 included (1) installation on GSFC servers and calibration of MIKE21, a 2-D finite element, flexible mesh model that possesses the capability to model high resolution hydrodynamics (50-300m) within the bay, as shown in Figure 9.19, and (2) extensive simulation and statistical analysis of water height data requirements for a range of bay scenarios including typical neap and spring tides (March 2006) and surge heights (Hurricane Isabel, September 2003).

One major conclusion from our work relates to the determination of SWOT satellite accuracies required for assimilation within coastal hydrodynamic models. Our results, shown in Figure 9.20, indicate that the anticipated SWOT SSH error spectrum is smaller than the modeling spectra of typical neap tide and surge simulations at 1 km resolution (green line). It is therefore sufficient to meet the needs for future modeling at 1 km resolution for the Chesapeake Bay Estuary. A summary of this work was presented at the September 2010 American Meteorological Society Meeting on Satellite Meteorology and Oceanography.

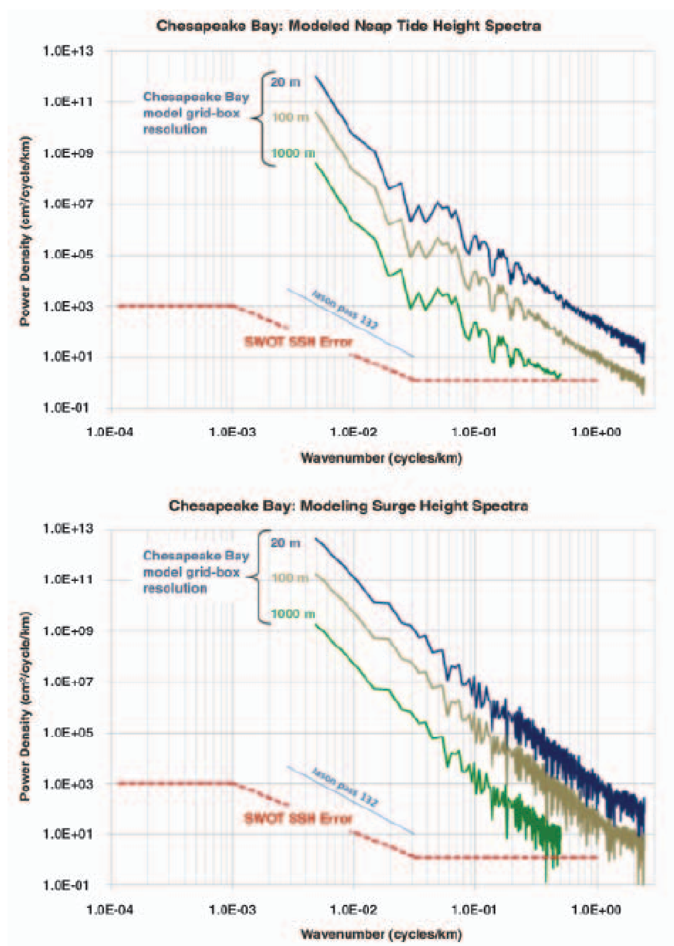


Figure 9.20. Power Density Spectra, for various modeled resolutions, of typical neap (Mar '06) and surge (Hurricane Isabel '03) water surfaces modeled by MIKE21, as compared to expected SWOT SSH error (After Borak et al, 2010).

A third project recently initiated is the modeling of the Atchafalaya River in Southern Mississippi, for improved flood estimation. This region, a low lying delta region known for overbank flooding, is chosen as it is being proposed as a field test site for a future SWOT field campaign. Work includes the hydrodynamic modeling of the Atchafalaya River over a three month period in spring 2006, using the LISFLOOD-FP model from the University of Bristol. Two-dimensional elevations are being compared with ALOS PALSAR data, a surrogate to the anticipated SWOT imagery. The modeling domain is shown in Figure 9.21.

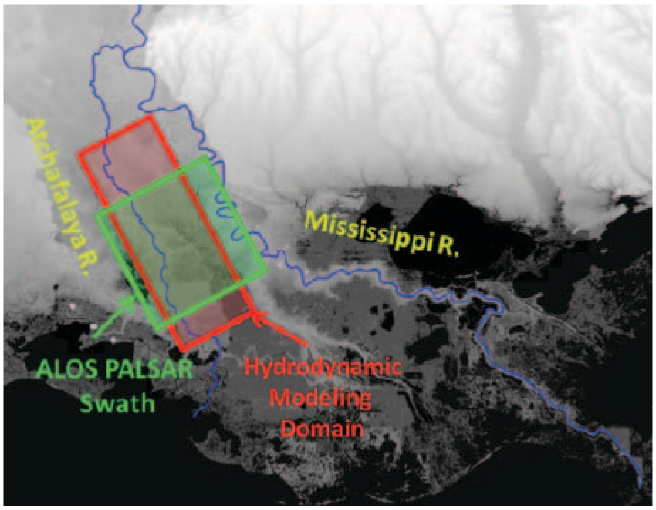


Figure 9.21. Modeling domain of the Atchafalaya River flooding project.

ASCENDS

The NASA Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission, recommended by the NRC Decadal Survey, is considered the technological next step following deployment of passive instruments such as the Japanese Greenhouse gases Observing SATellite (GOSAT, 2009) and the NASA Orbiting Carbon Observatory re-flight (OCO-2 expected in 2013). Using an active laser measurement technique, ASCENDS will extend CO_2 remote sensing capability to include uninterrupted coverage of high-latitude regions and nighttime observations with sensitivity in the lower atmosphere. The data will enable investigations of the climate-sensitive southern ocean and permafrost regions, produce insight into the diurnal cycle and plant respiration processes, and provide useful new constraints to global carbon cycle models. NASA's current plan is for launch in 2019-2020.

GSFC is supporting ASCENDS through technology development, instrument definition studies, and carbon cycle modeling and analysis. Dr. William Heaps is Principal Investigator for an Instrument Incubator Program (IIP) project to develop a broadband laser system with Fabry-Perot detection that may be a candidate for the ASCENDS instrument.

Figure 9.22. GSFC Airborne CO_2 Lidar Instrument in NASA Lear-25.

Laboratory for Atmospheres members also participate on technology projects, led by the Laser Remote Sensing Branch, which target instrument and mission development for ASCENDS. They play a key role in radiative transfer modeling, retrieval algorithm development, test instrument field deployment, and data analysis on the GSFC-developed CO_2 sounder instrument led by Dr. James Abshire in the Solar System Exploration Division, Principal Investigator for an ASCENDS-related IIP as well. Specific accomplishments related to the CO_2 sounder are described below. Based on experience and knowledge of carbon cycle science, GSFC scientists and engineers actively help to keep the technology development on track to best achieve the science objectives for ASCENDS. They also support the ASCENDS flight project by performing observing system simulations to establish science measurement requirements and to evaluate the impact of various mission technology options.

Accomplishments in 2010 supporting the ASCENDS mission definition include successful airborne experiments to measure CO_2 column densities. Specific results from the July 2010 demonstration of GSFC's CO_2 sounder instrument include:

- Demonstrated improved measurements of CO_2 absorption, some with simultaneous measurements of oxygen (potentially eliminating the need for a separate O_2 instrument).
- Demonstrated that the GSFC technique can determine range to the surface with sufficient precision to eliminate the need for a separate altimetry channel (and laser), which saves mass and power and simplifies the instrument.
- Demonstrated CO_2 and O_2 column line-shape absorption that compared well with theory.

- Comparison of average CO_2 columns with in-situ measurements showed expected altitude dependence.

ACE

The Aerosols, Clouds, and Ecosystems (ACE) mission is a NRC Decadal Survey Tier II mission. Aerosols and clouds are major factors in modulating global climate change and the ocean is a major sink of anthropogenic CO_2. The IPCC (2007) has noted that uncertainties about clouds and aerosols represent the predominant source of uncertainty that limits present climate prediction capabilities. In addition, increases in oceanic uptake of CO_2 are inducing ocean acidification that impacts marine ecosystems. ACE seeks to provide the necessary measurement capabilities to enable robust investigation of aerosols and clouds in global change during the 2020s, especially with regards to characterizing and understanding the processes that are occurring including the interplay between ocean ecology and marine aerosols. The plan is to fly one or two satellites in sun-synchronous polar orbit to provide high-resolution global measurements of aerosols, clouds, and ocean ecosystems (ocean color). In particular, the mission will provide major new measurement capabilities to enable dramatic steps forward in understanding the direct radiative role of aerosols in global climate change; the indirect aerosol effects via interactions with clouds and precipitation, and cloud processes, especially cloud microphysics; and to observe key properties of marine ecosystems and ocean carbon pools not presently available from existing sensors. The mission will take strong advantage of the potential synergy between advanced aerosol measurements and next-generation ocean color measurements where atmospheric correction, mostly for aerosol effects, is critically important to the quality of the ecosystem measurements. The current nominal plan is for a 2021 launch into low Earth orbit at an altitude of 400-450 km. With respect to aerosol and cloud measurements, it is the successor to the aging A-Train satellite constellation, specifically CloudSat, CALIPSO, MODIS, and POLDER (soon to be replaced by Glory). The ACE payload includes an advanced broad-swath ocean ecosystems radiometer, a nadir-pointing, seven-channel HSRL ($3\beta+2\alpha+2\delta$), a dual w- and Ka-band radar with limited scanning capability, as well as an advanced polarimeter for aerosol and cloud measurements. Broad-swath radiometers sensing in the infrared, microwave, and sub-millimeter spectral regions are also included in the optimal mission concept. An intermediate aerosol-cloud mission is EarthCare, a three-year ESA mission that may launch in the 2015 timeframe and will include three-channel, high-spectral-resolution lidar (HSRL) and a w-band radar, both nadir pointing.

The ACE Science Working Group, chaired by Dr. David Starr, is charged to develop the focused scientific questions and measurement requirements for this mission, and the corresponding mission and instrument concepts. GSFC scientists participate in every ACE science group including Aerosol, Clouds, Marine Ecosystems, Polarimeter, Lidar, Radar, Ocean Radiometer, and Suborbital and Cal/Val. In addition to science definition, GSFC instrument scientists and engineers are developing a number of airborne instruments (ACE simulators) to aid in mission definition and algorithm development, including an ocean ecosystem radiometer, the Ocean Radiometer for Carbon Assessment (ORCA), and the OSPREy system for ocean color radiometry field measurements; an advanced polarimeter, the Passive Aerosol and Cloud Suite (PACS); a new lidar system, the Cloud-Aerosol Transport System (CATS); a rebuilt w-band radar (Cloud Radar System, CRS), an updated submillimeter scanning radiometer (CoSSIR), and an updated microwave scanning radiometer (CoSMIR). We are also active in Ka-band radar in partnership with Northop-Grumman as part of an Instrument Incubator Program (IIP) award in 2010.

In the past year, significant progress was made in specification of science requirements and maturation of the mission and instrument concepts. A number of different mission design studies were conducted at both JPL and GSFC and a comprehensive report has been drafted, including detailed Science Traceability Matrices for each science discipline and each cross-discipline area. The various airborne instruments all progressed markedly. A number will have flights in 2011, e.g., for GLORY Cal/Val. ACE progress and plans were positively reviewed in November 2010. The briefing report is available at: http://dsm.gsfc.nasa.gov/ace/documents.html.

In 2011, further maturation of mission requirements and mission architecture options will be undertaken, and a comprehensive and robust TRL assessment will be initiated. In addition, various risk reduction activities will be undertaken, including initiation algorithm development appropriate to the proposed new sensor capabilities.

HyspIRI

The Hyperspectral Infrared Imager Mission (HyspIRI), a Tier 2 NRC Decadal Survey mission, is currently at the mission concept development stage (http://hyspiri.jpl.nasa.gov) with an expected launch date of 2021. Science goals address robust measurements of the biosphere and of the Earth's surface. The goal is to determine climate feedbacks related to: (1) ecosystem composition and function; (2) carbon emissions from biomass burning; (3) black carbon/dust effects on snow and ice; (4) evapotranspiration and water use; and (5) volcanic eruptions. HyspIRI will be in a polar low earth orbit and will obtain Earth surface observations at a 10:30AM equatorial mean local time. HyspIRI has two primary passive optical instruments, a visible through shortwave infrared (VSWIR) imaging spectrometer with 10 nm spectral sampling (380-2500 μm), and an eight band multispectral thermal infrared (TIR) imaging radiometer (4-12 μm). The VSWIR will enable seasonal assessments of ecosystem function and constituents (e.g., species, nitrogen, and carbon) and patterns for biodiversity. The TIR will enable weekly to monthly assessments of evapotranspiration, wildfires, and other hot targets. Both instruments have a 60 m spatial resolution, but data over open oceans will be averaged to 1 km samples. The VSWIR spectrometer is canted 4 degrees westward of nadir in order to minimize sun glint, and has a 150 km swath. The TIR has a much wider, 626 km swath. The equatorial revisit intervals are 19 days and 5 days, respectively for the VSWIR and TIR instruments. The TIR will acquire both night and day images, while the VSWIR will only obtain images during daytime periods.

HyspIRI is led by NASA/JPL, primarily for instrumentation development by Dr. R. Green (for VSWIR) and Dr. S. Hook (TIR). GSFC is a science partner, funded at approximately 15-20 percent support level under the leadership of Dr. E. Middleton. NASA Headquarters funding for GSFC in FY2011 is ~$700K, twice the FY2010 allocation. Several members of the Biospheric Sciences Branch (Drs. E. Middleton, R. Knox, and S. Ungar) serve on the NASA Headquarters-led HyspIRI Steering Committee and the HyspIRI Science Study Group, routinely contributing to the formulation of the mission via weekly telecoms, meetings, and briefings to NASA Headquarters and elsewhere on the technical status and readiness of the mission. Engineering participants from the GSFC Software Systems Engineering Branch are developing an Intelligent Payload Module (IPM) and other technologies to automate and streamline high data volume processing, and to enable on-board processing of low latency data products. The GSFC HyspIRI team has taken the lead in developing ecosystem product prototypes for the VSWIR imaging spectrometer. GSFC planned, led, and hosted a 2-day HyspIRI Science Symposium on Ecosystem Products in May 2010 and is currently planning to do this again in May 2011. These GSFC meetings supplement the three JPL-led HyspIRI Science Workshops held in California (2008, 2009, and 2010) to develop a consensus on the science questions; a fourth is scheduled for August 2011 in Washington, DC.

GEOCAPE

The Geostationary Coastal and Pollution Events (GEOCAPE) mission, as recommended by the NRC Decadal Survey as Tier-2, seeks to launch a geostationary platform over the Continental U.S. GEOCAPE seeks to understand: (1) the temporal and spatial scales of emissions and processes that control air quality over the continental U.S.; (2) the interaction between short-term coastal processes and open ocean and their impact on large-scale physical, ecosystem, and biogeochemical oceanic processes; and (3) the interactions between these processes and how they respond to and force climate change. Because of the short time and spatial scales of the above processes, it is crucial to use a geostationary platform that could provide repeated soundings throughout the day, and at high spatial resolution. Although the specific instruments to be flown in this mission are still being discussed, it is expected that they will include: a) high-resolution UV-Vis spectrometers to carry out measurements of species like NO_2, O_3, formaldehyde, SO_2, aerosol optical depth, and ocean color at different wavelengths; and b) near and thermal infrared detectors to measure CO and possibly increase the detection of ozone at different levels in the troposphere. At present, the expected launch date for this mission is after 2020. An official Science Definition Team is expected to be form in the next year.

GSFC supports GEOCAPE through participation in different study teams, in instrument development, and Mission Design Laboratory Studies. GSFC scientists (Dr. S. R. Kawa and A. Mannino) have led the Atmospheric and Ocean Science Working Groups, respectively. Several GSFC scientists (Drs. Kawa, and Mannino, Rodriguez, Chin, and Pickering) also participated in the Science Traceability Matrix working groups for both atmospheres and oceans, which finalized STMs in both areas. GSFC also contributes scientific expertise (Drs. K. Pickering, M. Follette, and N. Krotkov) in the atmospheric variability working group, specifically using simulations with NOAA's WRF regional model to understand the temporal and spatial variability scales for O_3, NO_2, SO_2, CO, and aerosols, and thus helping to define the needed temporal and spatial resolution of the GEOCAPE instruments. Oceanic variability studies (Dr. A. Mannino and M. Tzortziou) were carried out through measurements in the Chesapeake Bay and study of a suite of measurements from Aqua-MODIS and SeaWiFS. GSFC scientists also provide the leadership in the aerosol working group (Drs. M. Chin and O. Torres), whose mandate is to establish aerosol measurement requirements. GSFC scientists (Drs. Pickering and Krotkov) will play leadership roles in the DISCOVR-AQ Venture mission started this year, which will carry out systematic and concurrent observation of column-integrated, surface, and vertically-resolved distributions of aerosols and trace gases relevant to air quality as they evolve throughout the day. These measurements will contribute to further refinement of the science questions to be addressed and algorithms to be used in GEOCAPE.

IRAD funding to Dr. S. Janz is supporting modifications to the existing Airborne Compact Atmospheric Mapper to allow the deployment of a flight simulator and make the instrument a possibility for GEOCAPE deployment. In addition, GSFC carried out an Instrument Design Laboratory Study for the Coastal Ecosystem Dynamic Imager, which exceeds threshold requirements for the oceanic studies, and a Mission Design Laboratory study to consider the possibility of deploying the mission in multiple platforms to take advantage of potential opportunities in other agency and commercial vehicles.

JPSS

As background, the National Polar Orbiting Environmental Satellite System (NPOESS) was a tri-agency program between NASA and the Department of Commerce (specifically NOAA), and the Department of Defense (specifically the Air Force). It was designed to merge the civil and defense weather satellite programs in order to reduce costs, and provide global weather and climate coverage with improved capabilities above the current system. The NPOESS program experienced several challenges, including schedule delays and cost increases. The White House Office of Science and Technology Policy issued a fact sheet outlining a restructuring of the NPOESS program in FY 2011. Following are excerpts from the fact sheet:

> *The President's FY2011 budget contains a major restructuring of NPOESS in order to put the critical program on a more sustainable pathway toward success. The satellite system is a national priority—essential to meeting both civil and military weather-forecasting, storm-tracking, and climate-monitoring requirements. The major challenge of NPOESS was jointly executing the program between three agencies of different size with divergent objectives and different acquisition procedures.*

> *The new system will resolve this challenge by splitting the procurements. NOAA and NASA will take primary responsibility for the afternoon orbit, and DOD will take primary responsibility for the morning orbit. The agencies will continue to partner in those areas that have been successful in the past, such as a shared ground system. NOAA's portion will notionally be named the "Joint Polar Satellite System" (JPSS).*

The JPSS Program has been established and is in program formulation at GSFC. JPP is moving forward by supporting the launch of the NPP mission, and is in development with the Common Ground System. Subsequent JPSS missions include the J1 mission, now scheduled for a 2016 launch, and the J2 mission with an expected launch readiness date of 2018. GSFC support to the JPSS program will consist of providing the Senior Project Scientist, the JPSS Instrument Scientists, and recruiting new hires especially instrument scientists.

10. Applications

The Earth Sciences Division coordinates all science applications activities through a Division-level Applications Office that is tasked to engage the user community, the operational agencies in the government, and the private sector. Through this approach we have established many key partnerships with a broad array of users who can benefit from utilizing NASA Earth Science data and products to solve a multitude of societal issues. These collaborations result in the transition of our open source data products and models to the user community. As a part of these activities, we also provide initial training and familiarization for users. Our areas of science applications emphases are in the areas of Water Management, Disaster Management, Weather, Air Quality and Public Health, Agriculture, Ecological Forecasting, Climate, and Oceans. The majority of our projects are competitively selected and have a 3- to 4-year life cycle. For additional details, refer to Table 10.1 at the end of this section. This table further synthesizes each thematic area and its relationship to the sensors and the user communities involved. The following paragraphs provide representative examples of such collaborative work accomplishments.

Space Weather Impact

The GSFC Solar Shield project designed and implemented an experimental early warning system capable of forecasting the space weather effects on the northern American high-voltage power transmission system. Sun-Earth system data and models hosted at the GSFC Community Coordinated Modeling Center (CCMC) are used to generate two-level magnetohydrodynamics-based forecasts that provide 1-2 day and 30-60 minute lead-times. The Electric Power Research Institute (EPRI) represents the end-user, power transmission industry in this project. EPRI integrates the forecast products into an online display tool providing information about space weather conditions to the member power utilities. Figure 10.1 shows a ground-induced current (GIC) forecast versus the actual current measured at the high voltage transformer neutral.

Land Data Assimilation System (LDAS)

The Land Data Assimilation System (LDAS) consists of a land surface hydrology model that runs at 1/8th degree resolution

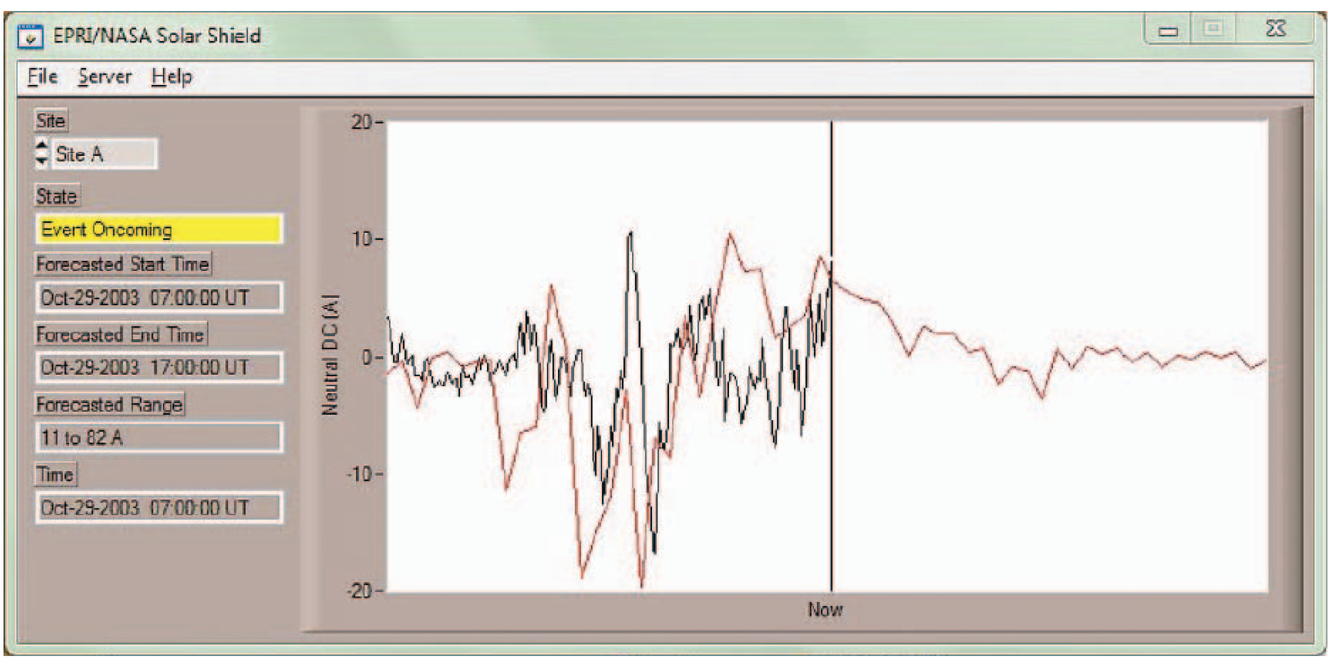


Figure 10.1. Screen capture of the end-user interface showing the GIC information and the model generated forecast (red color). The actual GIC is represented in black color.

across North America and 1/4th degree resolution globally. LDAS is also the operational land surface model for the NOAA and USAF weather forecast programs. A large number of Applied Sciences projects have leveraged the substantial LDAS investment made by GSFC. These LDAS systems have been run retrospectively starting in January 1979 and continue in near real-time, and are forced with precipitation gauge observations, satellite data, radar precipitation measurements, and output from numerical prediction models. Model parameters are derived from existing high-resolution vegetation and soil data. The model results support water resources applications, numerical weather prediction studies, numerous water and energy cycle investigations, and also serve as a foundation for interpreting satellite and ground-based observations. Future observations of water storage (e.g., soil moisture, temperature, snow) and fluxes (e.g., precipitation, evaporation, sensible and latent heat flux, runoff) will be used to further validate and constrain the LDAS predictions using data assimilation techniques.

Middle East Water Balance Using LDAS

This project delivers a land data assimilation system (LDAS) for mapping hydrological states and fluxes in the Middle East -North Africa (MENA) region and provides a focal point for international collaboration. Running at our partner center in Dubai, the International Center for Biosaline Agriculture, the MENA LDAS provides regional, gridded fields of hydrological states and fluxes, and serves as a basis for regional water resources assessments. The MENA region suffers from arid conditions and a growing population, and it will benefit greatly from more reliable information on the availability of renewable freshwater resources. We are configuring MENA LDAS to make use of NASA satellite data, local surface observations, and publicly available meteorological analyses. Figure 10.2 shows seasonal evapotranspiration mean values as computed using the MENA LDAS.

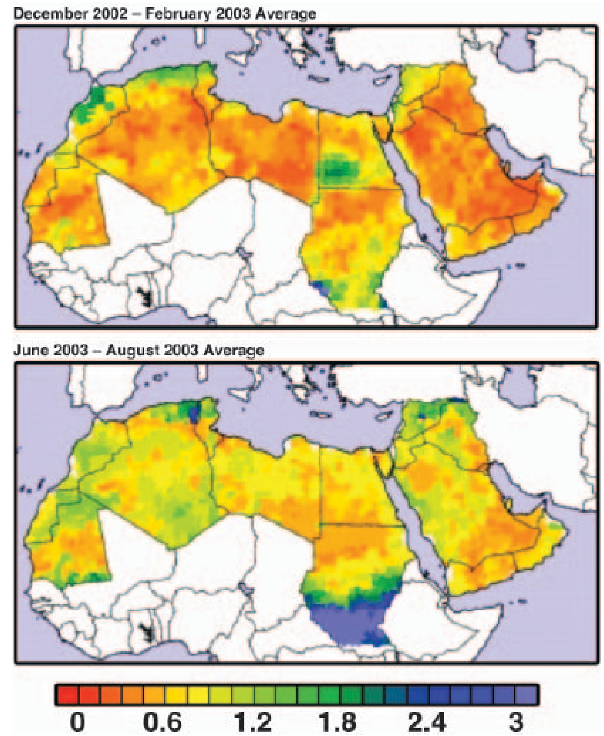


Figure 10.2. Evapotranspiration (mm/month) output from MENA LDAS for boreal winter (top) and summer (bottom).

SERVIR-Africa: Lake Victoria Basin Flood Potential Model

NASA in partnership with USAID has established a SERVIR node in Nairobi, Kenya at the Regional Center for Mapping for Resource Development (RCMRD). Through this project, we provide high-resolution (1 km) flood potential and flood forecast information for this highly populated and frequently flooded area. The model has been transferred to RCMRD, and NASA representatives have been providing training on numerous aspects of the model including calibrating, compiling, and running the model. In order to achieve the desired results for this model, the project is dependent on obtaining in-situ data (primarily rain gauge and river gauge data) from the national governments of Kenya, Tanzania, and Uganda through our partnership with RCMRD. The model as delivered to RCMRD was calibrated using the only data available at the time, specifically rain gauge and river gauge data from the Nzoia River Basin in Kenya. RCMRD continues to work toward acquiring additional data. Figures 10.3a and 10.3b show flood potential maps and model performance at the Nzoia basin test site.

Automatic Flood Mapping

An automated flood mapping capability has been developed in collaboration with the Dartmouth Flood Observatory and the NASA LANCE (Land Atmosphere Near Real Time capability for Earth Observing Systems) data processing system. Flood maps are produced in near real time for selected areas. Figure 10.4 shows such a map for the Zambezi and Kvango rivers in the southwest of Africa.

Monitoring of Groundwater

This is essential for local and regional water management and for improving our understanding of the role of groundwater storage dynamics in the water cycle. Groundwater storage varies spatially due to aquifer permeability and human pumping activities, and varies temporally in response to climate variability and human impacts. Our new ability to remotely monitor groundwater from space allows us to better understand, model, and predict groundwater changes on regional and continental-scales. One of the most promising methods for observing monitoring groundwater is using satellite-based gravimetry from the NASA Gravity Recovery and Climate Experiment (GRACE) satellites.

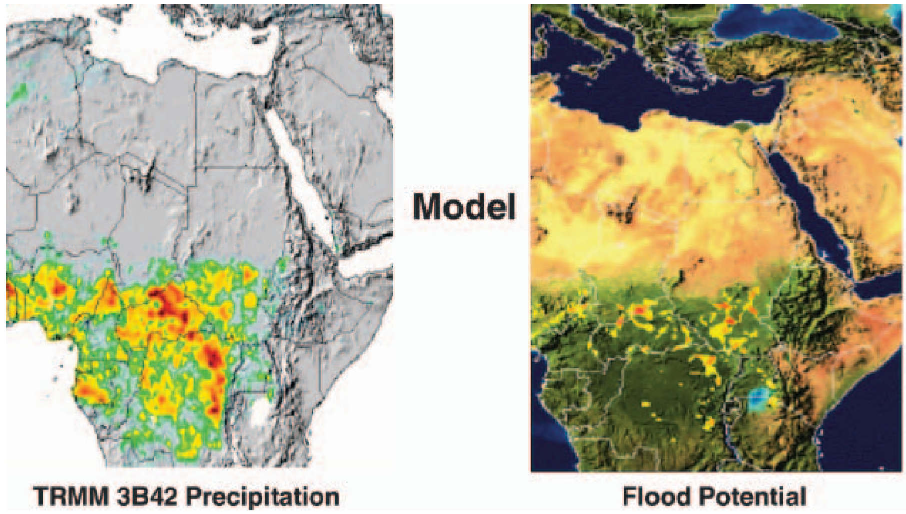


Figure 10.3a. TRMM Precipitation and SRTM data are used in global hydrologic models to forecast flood potential.

A recent study by Rodell et al. (2009) combined simulated soil-water variations with water storage-change observations from the GRACE Mission over Northwest India, to show that groundwater in the region is being depleted at an unsustainable rate. By combining satellite-based groundwater observations with local data, this approach provided an important regional perspective highlighting the impact of irrigation and human consumption on the water budget. Figure 10.5 shows a time series of depleting water table anomalies in the northwestern part of India.

Emissions Inventory

Air quality models are a critical tool in air quality management, and provide key inputs into decision making and policy development. A significant component of uncertainty in emissions is due to the fact that emission inventories are often out of date. Initial work focuses on the changes in OMI measurements of tropospheric NO_2 and boundary layer SO_2 column amounts that were observed during the 2008 Beijing Olympic Games (Figure 10.6). Prior to and during the Olympics we prepared plots of daily and 7-day running average tropospheric NO_2 and boundary layer SO_2 columns for the Eastern China region in near-real-time (within a day or two of the observation). These analyses allowed tracking of changes on short time scales as the emission reductions were implemented for the Olympics. Following the Olympics, we computed the monthly mean tropospheric NO_2 column amounts for a 0.5 x 0.5 degree region centered on Beijing through the end of 2008 and compared them with the corresponding months from the prior years of the OMI data record (2005, 2006, and 2007). These results showed an approximately 40-50 percent reduction in tropospheric NO_2 column over Beijing during the period of most stringent emission control (July and August). Reductions in OMI SO_2 column amounts were computed over a larger

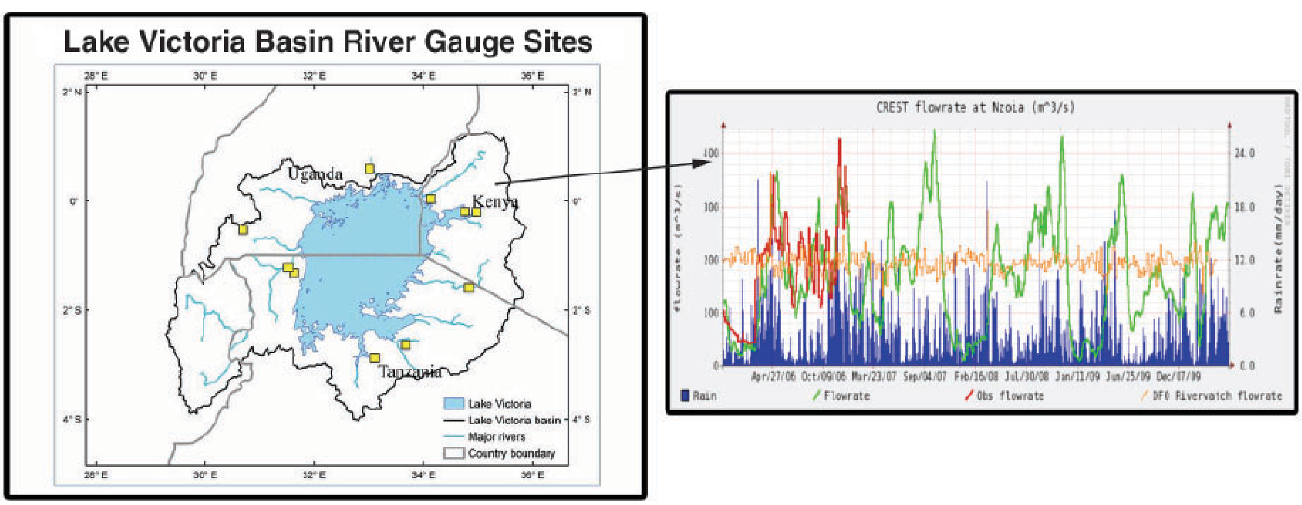


Figure 10.3b. Left diagram shows the Nzoia basin in the NW corner of the Lake Victoria. Right diagram shows measured meteorological and hydrological conditions in the Nzoia basin which are used to calibrate the model outputs. (Blue shows precipitation, red is the measured flow rate, green is the calculated flow rate, and orange is generated by the Dartmouth Flood Observatory.)

region, including industrial areas to the south of Beijing. Through this study a systematic analysis framework to provide rapid updates of emission inventories is being developed, demonstrated, and transitioned to operations. This framework is to be demonstrated in United States and Asia applications, and will support several important national and international activities. The project involves the University of Iowa, Argonne National Laboratory, and NASA GSFC.

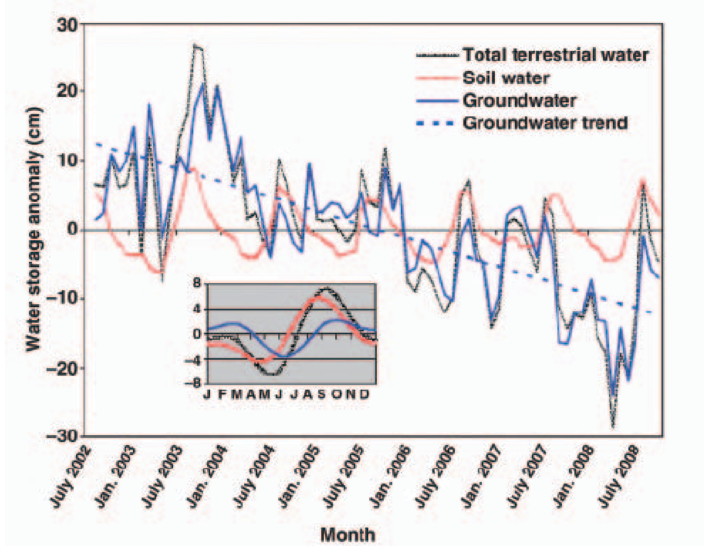


Figure 10.5. Monthly time series of water storage anomalies in northwestern India. (Rodell, M., I. Velicogna, and J.S. Famiglietti, 2009. Satellite-based estimates of groundwater depletion in India Nature, 460, 999-1002, 10.1038/460789a)

Utilizing Sensor Web during Critical Events

The EO-1operations team has developed a sensor web algorithm and an operating concept that is capable of linking multiple space assets to monitor many disasters or other critical events around the globe. This enables users to cost-effectively create customized data products and allows the use of open source tools such as Google Earth to display and analyze the data. Use of the Open Geospatial Consortium Standard provides for easy data access and interfaces. This is a significant step forward in collaborating with other space agencies during emergencies. The following figures (10.7a and 10.7b) show the recent volcanic eruption observed by EO-1 (visible) and EO-1 (SWIR) bands. Similarly, MODIS imagery of the Gulf of Mexico oil spill was used to target data acquisitions by the NASA EO-1 satellite.

For additional details on these and other projects, refer to Appendix A, Table A.3. This table describes in specific terms what products are being developed and transitioned for use by our partners.

Future Plans

The importance of the transition from research to applications has been emphasized in the NRC Decadal Survey and is a major priority for the Division. The Division will continue to apply and utilize research developments in Earth system science for the benefit of society. There will be several new sensors coming on-line in this decade. These include sensors on LDCM, GPM, NPP, SMAP, Aquarius, and Glory. We will be working closely with each of the missions to understand the future available data sets and products which will further enhance the Applied Sciences thematic research areas. Similarly, NRC Decadal Survey Tier I missions such as DESDynI and ICESat II offer great promise in our climate and disaster related applications. We will continue to emphasize the following critical areas:

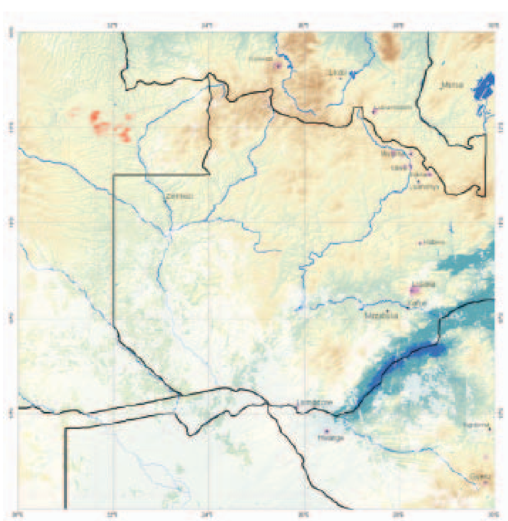


Figure 10.4. Red shows actual flooding conditions in the upper Zambezi River in Angola.

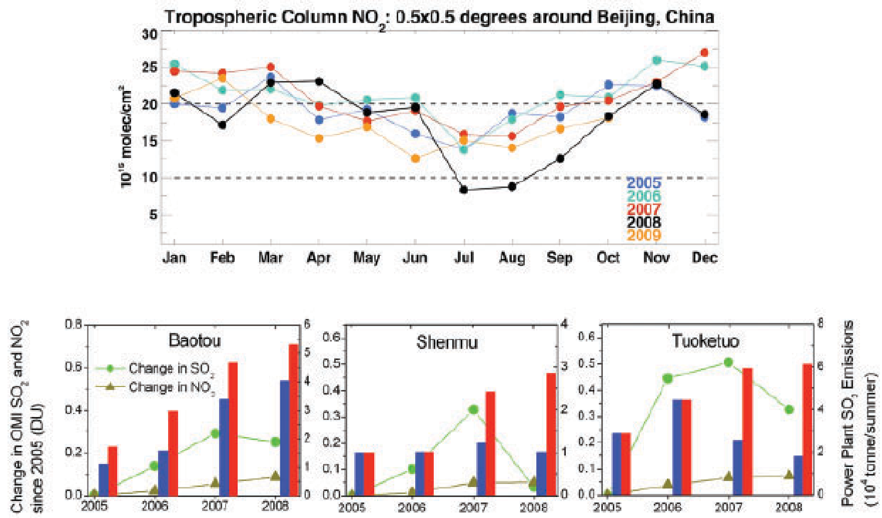
Water Management

The current emphases of our Water Management activities have been in the areas of: (1) stream flow and flood forecasting; (2) water supply and irrigation; and (3) drought monitoring and seasonal predictions. We will extend water management applications to include water quality and water resources. Recently, NASA, working with the USAID and the World Bank, has begun to assess the use of NASA satellite and modeling information to improve water management in the Middle East and North Africa (MENA) Nile basin and Indo-Gangetic Plain regions. We plan to develop Water Information System Platforms for these regions which will enable the users to better manage their hydrological resources.

Disaster Management

There will be significant attention given to expanding our Disaster Management portfolio to give greater emphasis on floods, drought, landslides, wildfires, and earthquakes. Global floods and landslides modeling and near real-time disaster monitoring efforts are underway by combining data from multiple sensors.

Figure 10.6. SO_2 and NO_2 emission inventories over China shows significant reduction during the Olympic season in 2008.



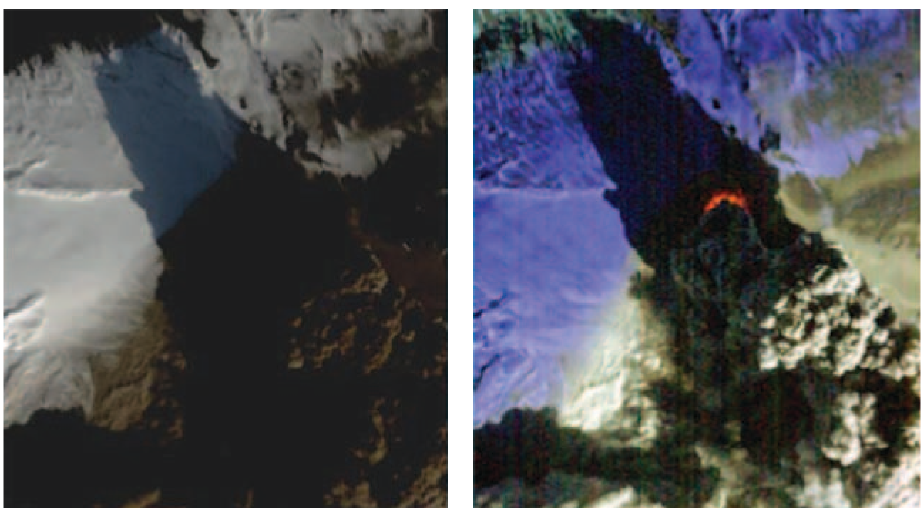
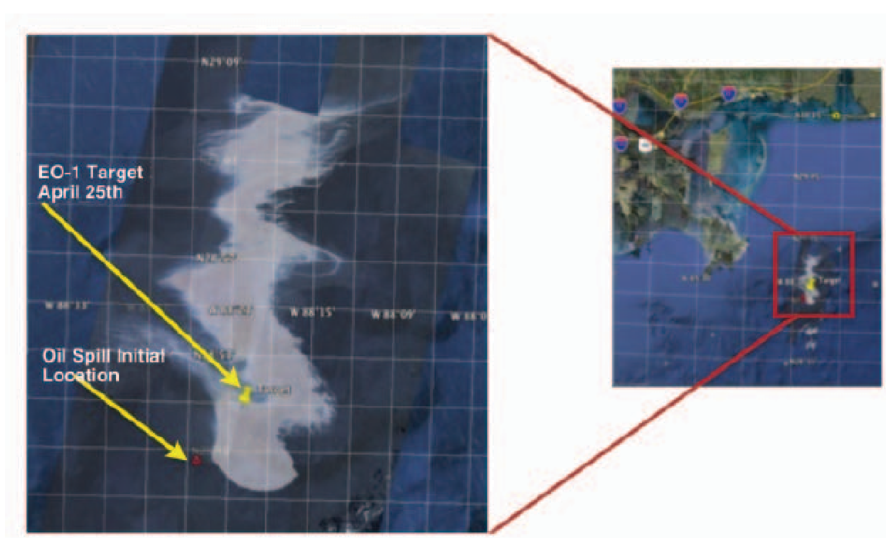


Figure 10.7a. On April 17, 2010, Hyperion instrument onboard NASA's Earth Observing-1 (EO-1) spacecraft acquired these images of the continuing eruption of Iceland's Eyjafjallajökull volcano. Left hand image shows actual plume and ashes in visible spectrum while right hand image shows brilliant unsullied ice and snow and the volcano's orange glowing hot spots.

Figure 10.7b. Right hand image shows MODIS image of the Gulf of Mexico oil spill that was used to obtain specific coordinates for targeting left hand side EO-1 image on April 25, 2010.



Public Health/Air Quality

We currently are conducting projects within the Public Health theme in the area of epidemiologic surveillance and risk mapping of vector-borne infectious diseases, e.g., Ebola, Malaria, and Avian Influenza. Future efforts under this theme will be to continue and mature our work on the Avian Influenza and expand it to include environmental health risks due to trace gases and aerosols. We have initiated use of Aura OMI NO_2 and SO_2 data in building updated and more comprehensive inventories of reactive nitrogen and sulfur compound emitters and in correlating OMI NO_2 (i.e., ozone precursor) with the atmospheric lightning data obtained from TRMM lightning mapper. We are also infusing these products in the EPA's Community Multiscale Air Quality model to produce improved air quality assessments and forecasts. MPLNET has begun supplying NRT boundary layer height products to NCEP to evaluate improved parameterizations of the planetary boundary layer.

Agriculture

Our current work under the Agriculture theme is to provide remote sensing products to improve global crop yield assessments and forecasts. We also have developed an invasive plant species forecasting system. In the future, we plan to put additional emphasis on partnerships that can use NASA Earth science products to improve agriculture practices to mitigate sediment nutrient loadings of water bodies. Additionally, we will examine opportunities to provide products to the growing field of carbon management. We continue to excel in the area of applied research for food security. We have initiated investigations on the potential impacts of climate change on agriculture production.

We also plan to study land degradation issues in the Indian subcontinent agricultural regions. Using satellite remote sensing technologies at a variety of resolutions, we will describe a methodology, develop maps of degradation, and transfer the knowledge to Indian partners. This research will leverage our studies (Figure 10.8) conducted for the Sahel region in Africa.

Ecological Forecasting

We plan to investigate and explore the applicability of research products for protecting species endangered by climate and land cover/use changes. This specifically includes fish species diversity in the African Rift Valley Lakes and Mekong region, and tiger populations in Southeast Asia.

Weather

We are involved in both space and terrestrial Weather-related applications. Primary activities are utilizing precipitation products for agriculture yield forecasting, and solar wind impact on U.S. high voltage electrical grid for the electric power industry. We plan to expand these areas to include space weather forecasting for aviation and improving the availability of accurate weather information to support the transportation and global mobility of people and material.

SERVIR

We are planning to expand our participation in international programs such as SERVIR, which is a multi-center data dissemination activity current working with Mesoamerica, and East Africa, and expanding to a number of other regions of the World. There is great interest by the USAID, NASA, and other world organizations to deal with multiple societal issues in the developing world including droughts, floods, malaria, rift valley fever, fires and aerosols, ecosystem changes, water resources, and impacts of climate change.

Climate

We plan to continue our applied research in the area of climate change impact on a wide variety of societal issues. This includes changes in sea ice on transportation safety and routes, Himalayan glacier melt and its impact on major river basins, water availability in heavily populated areas of the world, energy management, and transportation sector emissions.

Staffing

We currently have two full-time civil servant scientists, and approximately two contractor computer information specialists. This staff is further augmented on a team basis when we propose and execute our projects. However, an additional full-time civil service position is requested to enhance the core team capability. This is important to provide a more regular interface with NASA Headquarters and external agencies.

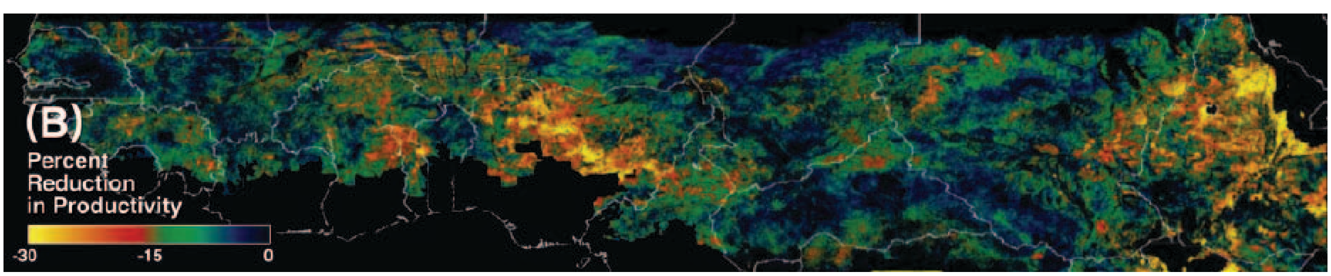


Figure 10.8. Map of land degradation in the Sahel based on precipitation and vegetation interactions.

Table 10.1. Contributions to Primary Application Areas

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA Products
Agriculture	• Development of remote sensing based products to improve estimates of global agricultural production • Drought monitoring and forecasting for agricultural applications • Famine and Food Insecurity Early Warning	– AVHRR – MODIS – Landsat – TRMM – AMSR – SRTM – All of the numerous satellite systems that contribute to the GMAO seasonal forecasts	– USDA/FAS – U.S. Drought Monitor and U.S. Drought Outlook (NOAA/NCEP) – USAID
Climate	• Climate impacts on: ° Energy ° Transportation emissions ° Agriculture ° Hurricane landfall ° Glacier melt ° Sea ice extent	– MODIS – AMSR – Landsat – ASTER – TRMM – SRTM	– Insurance companies – U.S. Navy – USAID – International Centre for Integrated Mountain Development – USDA – NOAA – Power companies
Disaster Management	• Monitoring and forecasting of global and regional floods and landslides • Development of post event flood maps • Development of NDVI, rainfall, humidity, and precipitable water data products for areas under drought and food security risk	– MODIS – Landsat – AMSR-E – TRMM – SRTM – AMSU – Meteosat – EO-1	– USDA/FAS – NOAA – USAID – International Red Cross – Pacific Disaster Center – SERVIR – United Nations' World Food Program – NCEP
Ecological Forecasting	• Invasive species forecasting • Decadal forest change algorithms and maps (e.g., Congo Basin)	– MODIS – SRTM – Landsat	– USDA – State governments – U.S. Geological Survey – USAID/CARPE

Table 10.1. (continued) Contributions to Primary Application Areas

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA Products
Public Health	• Monitoring of environmental factors (e.g., temperature, humidity, precipitation, NDVI anomalies) conducive to the spread of vector-borne diseases • Modeling of disease transmission and life cycle • Development of forecast models, risk maps, and early warning for malaria and avian influenza pandemic for Southeast Asia • Development of assessment models, risk maps, and early warning for Ebola, Rift Valley Fever and Marburg for sub-Saharan Africa and Arabian peninsula • Measurement and modeling of tropospheric aerosols and trace gases • Identification and quantification of natural and anthropogenic emissions sources • Aerosol measurement and modeling to improve weather forecasts and air quality forecasts	– AVHRR – MODIS – Landsat – SRTM – ASTER – TRMM – SRTM – EO-1 – Commercial satellite data – SIESIP portal – Meteosat – Aura/OMI – MODIS – MISR – CALIOP	– USDA – CDC – WHO – FAO – NASA - SERVIR Africa – Governments: Kenya, Tanzania, Uganda – DOD organizations – Local public health organizations – DOD – Global Emerging Infections Surveillance and Response System (DOD-GEIS) – NOAA – EPA – Atmospheric Science Modeling Division, U.S. EPA, Research Triangle Park, NC – Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC – NOAA NCEP
Water Resources	• Monitoring, modeling, and forecasting of meteorological and hydrological parameters for improved weather forecasting, water resource management, and drought and flood monitoring • Global data products for snow water equivalence, ground water storage, soil moisture, evapotranspiration, reservoir levels, and runoff data • Water resource forecasts at the regional level (Middle East and North Africa regions)	– MODIS – Landsat – TRMM – GRACE – SRTM – AMSR	– AFWA – NOAA – USAID – Arab Water Council – NOAA NCDC – U. Nebraska, Lincoln – Ethiopian Mapping Agency – Nile Basin Initiative – Regional Center for Mapping of Resources for Development – World Bank

Table 10.1. (continued) Contributions to Primary Application Areas

Application Theme	Areas of Concentration	NASA and Other Sensors/ Satellites Used	Partners Utilizing NASA Products
Weather	• Development of remote sensing based products to improve numerical weather forecasting • Improved soil moisture and temperature forecasts for agriculture and other applications • Near real-time data on rain rate wave spectra for hurricanes • Climate forecasts for improved management in the energy sector • Development of Space Weather data products and model forecasts • Forecasting of Space Weather impacts (geomagnetically induced currents) on the energy sector	– Imager GOES11 – AMSR-E – MODIS – LASCO/ SOHO – MAG/ACE – SWEPAM/ ACE – ISCCP – TRMM – Aura sensors – Aqua sensors	– NOAA – AF Res Lab – DOE – Electric Power Research Institute (EPRI) – North American power utilities (Via EPRI) – PJM Interconnection (operator of world's largest energy market) – Exelon Corporation (fifth largest U.S. electricity generator) – U.S. EPA – CARB

11. Education and Public Engagement

Sharing the new data and scientific knowledge that the Division generates with a broad cross-section of the public is the core goal for our Education and Public Engagement (EPE) activities. Our EPE programs and activities are designed for informing and educating the public, and to contribute to the educational and workforce development needs of the nation. To meet these challenges, ESD actively participates in, and in many cases leads, NASA's efforts to serve formal and informal education communities, and to provide data and information to all segments of the public. Our public communications emphasize new and compelling Earth system science results, remote sensing data from NASA's spaced-based and airborne missions, and predictive modeling results of the Earth's climate system. Likewise, we recognize that our audiences are diverse in their needs, wants, and expectations for scientific information, and as such we provide a portfolio of content and resources appropriate for these audiences (Figure 11.1).

Our EPE programs and activities are designed to be well integrated, strategic, and sustainable. They also are designed to coordinate activities between GSFC, NASA Headquarters, and other NASA centers. Within GSFC, this management coordinates activities between Center Management, the Office of Education, the Public Affairs Office (PAO), and individual mission EPE leads. Clearly, our EPE activities must be firmly grounded in the most relevant science but they also must use the best-accepted practices in education and science communication. Organizing all the ideas and approaches to education and public engagement has always been a challenge as many of them began as ad hoc initiatives. Many of our EPE initiatives were born out of new flight missions, which are by their nature, transitory (approximately 3-6 year prime missions). EPE implementation plans submitted for the 2009 NASA Earth Science Senior Review by EPE leads for Terra, Aqua, Aura, and ICESat (all ESD based) emphasized better cross-mission coordination and collaboration. The very successful "Know Your Earth" video which played in 291 movie theater lobbies through the Lobby Entertainment Network is one such example of cross-mission collaboration. The ESD supports and is fostering more such cross-mission EPE content development.

Figure 11.1. Examples of ESD EPE activities. Left: ESD scientist working with a middle-school student from Prince George's County, MD, during the Center's Summer of Innovation activities. Right: NASA's Earth Dome set up on the National Mall in Washington, DC, during the 40th Anniversary celebration of Earth Day.

The Division takes a "customer-oriented" approach to education and engagement by tailoring our communications efforts to meet the needs of our targeted audiences, which include:

- Formal Educators
  - K-12 teachers, students, and trainers of teachers
  - Two-year college faculty
  - Four-year college faculty and students
  - Graduate students
  - Tribal college students
- Informal Educators
  - Museums and science centers
  - Interpretive staff at national parks, nature centers, and zoos
  - Youth programs (after school programming, Girl Scouts, 4-H, etc.)
  - Citizen science groups and programs
- Decision makers (through work with GSFC and NASA Headquarters offices of congressional affairs)
- General public (through news media, electronic media, and special events)

To help inspire, engage, and develop the next generation of Earth scientists, and build an informed citizenry, the ESD is involved in a number of programs and activities, including:

- Undergraduate and graduate summer programs providing opportunity for students and NASA mentors to interact.
- Programs with historically minority colleges and universities.
- Adjunct professorships at colleges and universities.
- Direct support of graduate student research topics that result in mutual advantage to the universities and to the ESD.
- Membership in thesis committees.
- Courses taught by ESD scientists.
- Post-graduate programs.
- Professional development for community college faculty.
- Professional development for tribal college instructors.
- Professional development programs for K-12 educators.
- Development and distribution of a wide variety of classroom-ready activities.
- Professional development programs for informal educators.
- Development and distribution of a variety of informal education products and programs.
- Formal/informal education collaboration with museums and science centers.
- NASA's Applied Sciences' DEVELOP program for incubating application ideas and contributing to building capacity in the student science community.

Over the next five years, the Division seeks to focus and sharpen its delivery of EPE content to the public, public media, the research community, policy makers, and formal and informal educators/students. Under the leadership of the Division's EPE coordinator who reports to the director of the ESD, the priorities for the new science stories and EPE content/materials are being established for each of our target audiences. An Earth scientist serves as the Program Coordinator, leading the formulation of ideas for education and outreach and suggesting implementation strategies to the ESD director. A major goal in the Division's EPE strategy is to develop and build upon the linkages across the many different missions, EPE staff, and activities within the Division, the bulk of which are funded separately for mission-specific goals. Through these activities, our EPE staff, the Scientific Visualization Studio, and the mission-based EPE staffs have regular interactions with the GSFC and NASA Headquarters' Office of Public Affairs and Education Offices, to help promote a clear, consistent EPE theme and an efficient approach. We also work within the GSFC Public Engagement and Education Council (PEEC) to help organize and coordinate a coherent and portfolio-based approach to the Center's EPE plans and goals, plan for large public events, as well as design new content for the current and future GSFC Visitor Center. EPE staff also work in science advisory capacities within the newly-formed Earth Science Education and Public Outreach Forum (SEPOF), which is one of four NASA-funded forums to better coordinate and centralize NASA's EPE efforts. The ESD will continue to work closely with NASA Headquarters to establish performance assessment metrics.

Our EPE program works closely with various GSFC EPE Working Groups to identify and make available resources needed for special projects. These working groups were established to encourage coordination in the development and evaluation of our programs and products. While they have evolved over the years, the current groups are listed below:

- Science Communications (aiming at assisting scientists interested in EPE)
- Professional Development (for the EPE community in areas such as evaluation tools and techniques)
- Formal Education
- Informal Education

All four of the Working Groups work closely with and include representation from the GSFC Education Office and individual Earth Science missions. Details on the formal/informal working groups and the working group objectives follow:

Formal Education

Our goal is to target our communications toward curriculum decision makers at the state and district levels, and infuse Earth science imagery and information into the science, math, and geography curriculums at all grade levels (kindergarten through graduate). We will increasingly promote the complementary use of real NASA remote sensing data along with models in inquiry-based lessons designed to instruct about NASA Earth sciences content. Working with the ESD EPE coordinator, we have been successful in planning, organizing, and supporting large educational events such as those at the National Mall during Earth Day 2010, to celebrate the NASA Administrator's Summer of Innovation activities, and to produce materials and teacher kits for Earth Science Week 2010, among others. We are also working with NASA Headquarters and the Office of Education to revitalize GSFC's partnership with the Global Learning and Observations to Benefit the Environment (GLOBE) program, which is planning a major climate measurement campaign for students all over the world in the fall of 2011. This program emphasizes hands-on science measurements to engage and educate students throughout the world and is a natural fit for NASA's science measurements and educational content.

Informal Education

Our efforts focus on building, sustaining, and expanding partnerships and collaborative efforts with informal education institutions and professional groups, and with professional communications and science advocacy organizations. We target groups that demonstrate extensive and well-proven effectiveness with the public (for example, major science centers and museums, and agency partners such as the National Park Service and the U.S. Fish and Wildlife Service). Our main delivery mechanism is through professional development of informal educators, via workshops and presentations at professional conferences. We also partner with institutions to create new venues for showcasing ESD data and science content. For example, we provide major data sources for Science on a Sphere programs and programming for the UniView Dome and Magic Planet, and we make these datasets and the attendant knowledge freely available.

An objective of the working groups is to clearly identify target audiences, to quantify their perceptions of NASA's Earth science programs, and to find ways to inform and educate them as to the knowledge and value we bring forth. In parallel, the ESD will work with NASA Headquarters and the Earth SEPOF to establish the proper communication channels in reaching out to this segment of the public.

The EPE Working Groups exist to improve communications and to ensure that our programs and products are inclusive, effective, and efficient. The EPE efforts need to focus on mission measurements and science. The overarching strategy must combine the publicizing of new results along with integrating these results into the mission of the Division. To be successful, the working groups must promote the successes and results of individual flight missions and/or laboratories, while working to integrate these results with the interests, cognitive abilities, and technological capacities of their target audiences. While the individual working groups maintain autonomy, they work cooperatively to exchange ideas and support each other's efforts. Such a decentralized model can work well by delegating and distributing the burden of work and cost while bypassing decision-making bottlenecks that are inherent in more traditional top-down management hierarchies. ESD EPE programs and products will emphasize information assets that are unique to the ESD: (1) our new science results; (2) our measurement capabilities and data products; and (3) our data integration and analysis tools, and predictive models.

Part III

Appendices

Appendix A. Missions and Application Activities

Table A.1. Missions in Development

Mission Name	Launch Date	Mission Description	Center Lead
Glory	Feb. 2011	Aerosols measurements; total solar irradiance (TSI)	GSFC
Aquarius	June 2011	To collect sea surface salinity (SSS) data over the global oceans	JPL
NPOESS Preparatory Project (NPP)	Oct. 2011	To provide continuity in measurements between EOS and NPOESS programs and pre-operational risk reduction	GSFC
Landsat Data Continuity Mission (LDCM)	Dec. 2012	To provide continuity for land use/land cover change	GSFC
Global Precipitation Measurement (GPM)	July 2013	Global Water Cycle precipitation measurements	GSFC
Geostationary Operational Environmental Satellites (GOES) R series	2015	To provide a constant vigil for the atmospheric “triggers” for severe weather conditions	GSFC
Joint Polar Satellite System Program (JPSS)-1	2015	To provide measurement of various parameters for operational use	GSFC

Table A.2. NRC Decadal Survey Recommended NASA Missions

Mission Name	Mission Description	Concept Instruments	Center Lead
Near-Term Launch (2013-2018)			
ICESat II	Ice sheet height changes for climate change diagnosis	Laser altimeter	GSFC
SMAP	SMAP soil moisture and freeze/thaw for weather and water cycle processes	L-band radar L-band radiometer	JPL
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	L-band InSAR Laser altimeter	JPL/GSFC
CLARREO (NASA portion)	Solar radiation; spectrally resolved forcing and response of the climate system	Absolute, spectrally resolved interferometer	LaRC
Mid-Term Launch (2019-2024)			
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	Backscatter lidar Multiangle polarimeter Doppler radar	GSFC
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	Multifrequency laser	GSFC/LaRC
GEOCAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	Hyperspectral spectrometer	LaRC/GSFC
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	Hyperspectral spectrometer	JPL
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	Ka-band wide swath radar C-band radar	JPL
Long-Term Launch (2024+)			
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	Doppler lidar	TBD
GRACE II	High-temporal resolution gravity fields for tracking large-scale water movement	Microwave or laser ranging system	TBD
LIST	Land surface topography for landslide hazards and water runoff	Laser altimeter	TBD
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	UV spectrometer IR spectrometer Microwave limb sounder	TBD
SCLP	Snow accumulation for fresh water availability	Ku and X-band radars K and Ka-band radiometers	TBD
PATH	High-frequency, all-weather temperature and humidity soundings for weather and forecasting and SST	MW array spectrometer	TBD

Table A.3. Application Activities

Application Theme	Project	NASA & Other Sensors/Sat. Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Agriculture	Drought Index for agriculture applications	Numerous satellite systems contributing to GMAO seasonal forecasts	U.S. Drought Monitor and U.S. Drought Outlook (NOAA/NCEP)	– Forecasts of soil moisture for 3 months – Provided each month	Statistical analysis performed on GMAO seasonal forecasts	Improved delineation of current drought state and a better estimation of future drought
	FEWSNET (Famine Early Warning System Network)	MODIS Landsat NOAA AVHRR TRMM SRTM AMSR-E Meteosat	USAID, United Nations' World Food Program	– NDVI/mo – Decadal rainfall – Modeled vegetation – Humidity – Precipitable water (3 mo. future)	Models predicting biophysical parameters 1, 2, and 3 months in advance	Early warning of flood and drought in Africa for food security
	Land data assimilation system for famine early warning	MODIS Landsat NOAA AVHRR TRMM SRTM AMSR-E Meteosat	USAID	Seasonal food security outlook maps	NASA FEWSNET Land Data Assimilation System (FLDAS)	Early warning for food security
	NASA LIS and water cycle observation for global crop production	MODIS Landsat NOAA AVHRR TRMM SRTM AMSR-E	USDA	Soil moisture data for crop yield forecasting	Land surface modeling and data assimilation tools	Improved crop yield forecast
	Cereal price forecasting in West Africa	MODIS	USAID	NDVI/mo	Integrated NDVI data into an economic model	Improved cereal price forecast

Table A.3. (continued) Application Activities

Appl. Theme	Project	NASA & Other Sensors/ Sat. Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Climate	Climate impacts on energy and transportation emissions	N/A	PGM Power Company	Climate model simulations	Downscaled regional climate model results	Improved energy and air quality management approaches
	Climate models for agriculture decision support	Not specified	USDA NOAA	NASA global climate model outputs	Downscaled regional climate model results to improve agrotechnology decision support	Improved multi-year crop yield forecasts
	Hurricane and landfall climate	N/A	Aspen Reinsurance Company	Statistical hurricane landfall 10-year record	Statistical analysis capability	Improved risk management
	Himalaya glacier melt	MODIS TRMM SRTM ASTER Landsat	USAID ICIMOD	Glacier maps, stream flow, snow and glacier melt rate	Utah Energy Balance (UEB) snow and glacier melt data integrated into USGS GeoSRM	Improved water management and flood disaster mitigation
	Sea ice forecasting for ship routing	MODIS AMSR	U.S. Navy	Sea-ice extent forecasts	Sea-ice extent products integrated into U.S. Navy Polar Ice Prediction System (PIPS)	Improved maritime transport and safety

Table A.3. (continued) Application Activities

Appl. Theme	Project	NASA & Other Sensors/ Satellites Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Disaster Mgmt.	Global floods and landslides monitoring and forecasting	MODIS Landsat AMSR TRMM SRTM AMSU	– International Red Cross – Pacific Disaster Center – SERVIR – USAID	– Cross sensor calibrated precipitation 3B42, flood forecast and flood potential maps (ea. 3 hours)	Global VIC flood model	Global early warning for flood and landslide potential
	SERVIR Africa	MODIS Landsat EO-1 TRMM SRTM AMSR AMSU	– RCMRD Nairobi, Kenya – Disaster management agencies in Kenya, Tanzania, Uganda, and Ethiopia	– Calibrated precip. 3B42, flood forecast and flood potential maps – NDVI (monthly anomalies)	– VIC flood model – Flood mapping algorithms	Early warning for flood potential and Rift Valley fever outbreak
	Global flood mapping	MODIS EO-1	– USAID – International Red Cross – UN – FEMA	– Near real time daily global flood map	Flood mapping algorithm	Early disaster warning
Ecological Forecasting	Congo Basin monitoring using satellites (CARPE)	Landsat MODIS SRTM	– USAID CARPE	– Improve decadal forest change mapping product (2005) – Corrected & mosaicked Landsat imagery – State of Forest report	DFCM algorithm to be transferred to the Observatoire Satellital des Forêts d'Afrique Centrale for operational monitoring in Kinshasa	Reduce the rate of forest degradation and loss of biodiversity in the Congo Basin
	Prediction of Africanized honey bee distribution and migration	MODIS	– USGS – USDA – State governments	– Time dependent maps of bee habitats in relation to pollen and nectar availability	Integration of MODIS products to USGS invasive species model	Improved decision support for honey production and agricultural pollination

Table A.3. (continued) Application Activities

Appl. Theme	Project	NASA & Other Sensors/ Sat. Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Public Health	Malaria Modeling & Surveillance	AVHRR MODIS Landsat ASTER TRMM SRTM EO-1 SIESIP Commercial satellite data	– DOD – Local public health org.	– Locations of potential larval habitats – Current and future malaria prevalence – Malaria transmission under various scenarios	– Habitat Identification Model – Prevalence Model – Agent-Based Discrete Event Transmission Model	Reduction in morbidity & mortality due to malaria
	Predicting Zoonotic Hemorrhagic Fever Events	AVHRR MODIS TRMM Meteosat SRTM	– DOD Global Emerging Infections Surveillance and Response System – WHO/FAO	– Risk maps of zoonotic hemorrhagic fever monthly and on demand, for Sub-Saharan Africa and Arabian Peninsula	– Spatial and seasonal classification algorithms of endemic regions – Ecoclimatic modeling for risk maps	Early-warning system for Ebola, Rift Valley Fever, and Marburg events
	Avian Influenza Risk Prediction	ASTER MODIS TRMM SRTM	DOD USDA	Risk maps showing migratory birds near vulnerable wetland and poultry populations	Methodology for risk map generation	Early-warning for Avian Influenza and other pandemic influenzas
	Environmental Forecasting Capability	MODIS MISR CALIOP	NOAA NCEP	GOCART global aerosol model	GOCART aerosol model code implementation in the NOAA Global Forecast System	– Improve national weather forecasts – Improve air quality (PM2.5) forecasts
	Dynamic Updating of Emissions for Air Quality Analysis	OMI	EPA	NO_2 and SO_2 tropospheric concentration	Near real-time emissions inventory map	– Improved air-quality monitoring and forecasting

Table A.3. (continued) Application Activities

Appl. Theme	Project	NASA & Other Sensors/Sat. Used	Partner Utilizing NASA Products	Data and Products Provided	Specific Algorithms or Models Transferred	Potential Societal Benefits
Water Resources	Enhanced GRACE Water Storage for Drought Monitors	GRACE TRMM MODIS Landsat	– NOAA/ NCDC – Univ. Nebraska, Lincoln	Weekly groundwater and soil moisture anomalies	Data assimilating version of catchment land surface model	Improvement in U.S. and North American Drought Monitor products
	Middle East—North Africa Land Data Assimilation System (Arab LDAS)	GRACE TRMM MODIS Landsat	– USAID – Arab Water Council	3-hourly and longer groundwater, soil moisture, irrigation water usage, evaporation, and runoff maps	Land data assimilation system optimized for the MENA region	Cooperation among Arab nations on water resources assessment and planning
	NILE Hydrology and Water balance	TRMM MODIS Landsat AMSR SRTM GRACE	– USAID – Nile Basin Initiative – RCMRD – Ethiopian Mapping Agency	Land-cover maps, evapotranspiration rates, river flow rates, water balance estimates	NASA Land Data Assimilation System, ALEXI ET model	Water management in Nile countries
Weather	Space Weather Impacts on Energy Sector	LASCO/SOHO MAG/ACE SWEPAM/ACE	– Electric Power Research Institute – North American power utilities	Forecasts of geomag. currents in the North American grid. (i) 1-2 day forecast (ii) 30-60 minute forecast	– Algorithms for optimizing the GIC modeling process – Incorp. into SUNBURST decision support tool	Power transmission industry to mitigate the potentially catastrophic effects of GIC on the grid(s)

Appendix B. Education and Public Engagement Activities

Below are the education and public engagement activity details mentioned in the main text of this report.

B.1) Education

Formal Education

College Student Programs

The following have been supported by the Division in the past and represent the types of programs the ESD expects to maintain in the future:

- **Undergraduate Students Summer Program:** This program is organized through the University of Maryland, Baltimore County.
- **Graduate Student Summer Program:** Consisting of roughly 10 students, this program is organized by the GEST Center of the University of Maryland, Baltimore County.
- **Research and Discover Summer Internship Program with the University of New Hampshire (UNH):** The objectives of this program are to recruit outstanding young scientists into research careers in Earth sciences and Earth remote sensing, and to support Earth science graduate students enrolled at UNH through a program of collaborative partnerships with NASA GSFC scientists and UNH faculty.
- **The NASA Academy:** Designed to develop space leaders at a number of NASA Centers, this educational program has targeted late undergraduates/early graduate students. This program is managed by the GSFC Office of Higher Education.

Undergraduate interns from the DEVELOP Program present their results at the annual GSFC intern poster celebration.

Joint Centers Collaborative Support of Graduate Students

The Joint Centers have fostered partnerships with academic institutions wherein the two entities can employ their complementary talents and facilities to enhance Earth and space science research and the education of present and future generations of scientists. A list of the active Joint Centers is shown in Table B.1:

Table B.1. Partnerships between ESD and the Academic Community

Center for Climate Systems Research, with Columbia University Earth Institute
Center for Earth-Atmospheric Studies (CEAS) with Colorado State University
Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) with Howard University
Cooperative Institute of Meteorological Satellite Studies (CIMSS) with University of Wisconsin, Madison
Earth System Science Interdisciplinary Center (ESSIC) with University of Maryland, College Park
GSFC Earth Sciences and Technology Center (GEST Center) with University of Maryland, Baltimore County
Joint Center for Earth Science (JCES) with University of New Hampshire
Joint Center for Earth Systems Technology (JCET) with University of Maryland, Baltimore County
Joint Interdisciplinary Earth Science Information Center (JIESIC) with George Mason University
Two cooperative agreements with the Applied Physics and Applied Math Departments of the Columbia University School of Engineering

These partnerships are meant to result in joint research proposals and joint efforts to provide instruction and training. To foster such interactions, coordinated efforts have taken place at the Joint Centers to identify students (as they enter graduate programs they are about to choose their thesis topic) whose interests are shared by a university professor and an ESD scientist. In such cases, ESD pays for the student support for the first year and the university professor and the ESD scientist share the responsibility for supporting the student to the completion of his/her degree. Typically, the ESD scientist becomes a member of the student's thesis committee. The students are encouraged to spend time at GSFC. See the table below for the list of graduate students supported.

Table B.2. Graduate Students Selected at the Joint Centers

Student Name	University	Field	Advisor/Sponsor	Year Started/ Year Finished (Expected)
Toshihisa Matsui	Colorado State University (CSU)	Aerosol effects on the microphysics of clouds	Roger Pielke Sr. (CSU) Wei-Kuo Tao (GSFC)	2002/Fall 2006
Derek Posselt	Colorado State University (CSU)	Assimilation of satellite-observed cloud properties into GCMs	Graeme Stephens (CSU) Arthur Hou (GSFC)	2003/Fall 2006
Kevin Mallen	Colorado State University (CSU)	Radar analyses and studies of precipitation systems	Michael Montgomery (CSU) Scott Braun (GSFC)	2004/Fall 2008/ TBD
Maike Ahlgrimm	Colorado State University (CSU)	GLAS-derived cloud climatologies	Dave Randall (CSU) Jim Spinhirne/Steve Palm (GSFC)	2005/Fall 2007
Kelley Wells	Colorado State University (CSU)	Remote sensing of aerosol absorption	Sonja Kiedenweis (CSU) Lorraine Remer (GSFC)	2006/ Spring 2009
Nicholas Parazoo	Colorado State University (CSU)	Carbon cycle modeling	Scott Denning (CSU) Randy Kawa/Wei-Kuo Tao (GSFC)	2007/ Spring 2010
Nick Guy	Colorado State University (CSU)	Ground based radar data	Stephen Rutledge (CSU) Wei-Kuo Tao (GSFC)	2008/ Spring 2011

Table B.2. (continued) Graduate Students Selected at the Joint Centers

Student Name	University	Field	Advisor/Sponsor	Year Started / Year Finished (Expected)
Shaima L. Nasiri	University of Wisconsin	Satellite-MODIS observed cloud properties	Steve Ackerman (UW) Michael King/Steven Platnick (GSFC)	2002/Fall 2004
Robert Holz	University of Wisconsin	Spectral properties of clouds and impact of clouds on climate	Steve Ackerman (UW) Matthew McGill (GSFC)	2004/Fall 2005
Brent Maddox	University of Wisconsin	MODIS and clouds	Steve Ackerman (UW) Steven Platnick (GSFC)	2006/Fall 2009
Chris Danforth	UMCP	Chaos processes in general circulation models/GCMs	David Levermore/Eugenia Kalnay (UMCP) Robert Cahalan (GSFC)	2002/ Winter 2006
Elizabeth Brabson	UMCP		Ragu Murtugudde (UMCP) Siegfried Schubert (GSFC)	2003/ Fall 2008 (M.S.)
Elana Klein Fertig	UMCP	GCM data assimilation	Eugenia Kalnay (UMCP) Ricardo Todling (GSFC) Ron Gelaro (GSFC)	2003/Fall 2007
Wilfred Schroeder	UMCP	Fire characterization over large scales using satellite data	Ruth DeFries (UMCP) Jeff Morisette (GSFC)	2004/ Spring 2008
Christopher Blakely	UMCP	Spectral approximations of discrete data defined on a sphere	Ferd Baer (UMCP) Tom Clune (GSFC)	2004/ Spring 2009
Hezekiah Carty	UMCP	Interactions between the oceans and the atmosphere as related to TRMM observations	Sumant Nigam (UMCP) Eric A. Smith (GSFC)	2005/MS 2006, Ph.D. 2009
Stephen Penny	UMCP	Innovative numerical methods in geophysical problems	Charles D. Levermore (UMCP) Warren Wiscombe (GSFC)	2005/ Spring 2009
Karl Wurster	UMCP	Land use and energy using remote sensing	Ruth DeFries (UMCP) Marc Imhoff (GSFC)	2006 / (Spring 2010)
Felicita Russo	UMBC	Micropulse lidar extinction measurements using Raman Lidar	Ray Hoff (UMBC) David Whiteman (GSFC)	2002 / Summer 2007
Antonia Gambacorta	UMBC	Raman Lidar studies of water vapor, cirrus cloud optical depth, particle size, and ice water content	Ray Hoff (UMBC) David Whiteman (GSFC)	2003/ Winter 2008

Additional Interactions

Interactions with graduate and undergraduate students also take place outside the formal programs outlined above, and are encouraged by all levels of management in the Division. About 50 students spent time in the Earth Sciences Division during the 2010 year. In addition, many members of the ESD staff are part of M.S. and Ph.D. thesis committees, supporting students at universities from across the country. In the past, much of this collaboration has been through the Joint Centers. See the next table for a list of ESD scientists that were thesis advisors.

Table B.3. ESD Scientists that were Thesis Advisors or Members of Thesis Committees in Academic Year 2010

Scientist		
Michael Bosilovich *	James Irons *	Rolf Reichle *
Scott Braun *	Ralph Kahn *	Lorraine Remer * (2)
Molly Brown *	Edward Kim *	Matthew Rodell * (2)
Brian Cairns * (2)	Allegra LeGrande * (3)	James A. Smith * (2)
Mark Chandler *	Thorsten Markus * (3)	David Starr *
Peter Colarco *	Ron Miller *	Wei-Kuo Tao * (4)
Jim Collatz # *	John Moisan *	Maria Tzortziou # *
Temilola Fatoyinbo *	Ross Nelson * (4)	Michael Way #
Ann Fridlind *	Thomas Neumann # (2)	David Whiteman * (2)
Gerald Heymsfield * (2)	Dorothy Peteet # * (2)	Xiaoxiong Xiong *
Peter Hildebrand *	Christa Peters-Lidard * (2)	
Marc Imhoff *	Steven Platnick *	

Masters committees   * Ph.D. committees

The table below lists courses taught by ESD scientists.

Table B.4. Courses Taught by ESD Scientists in Academic Year 2010

Location	Title of Course	Instructor
Barnard College	Agricultural and Urban Land Use	Cynthia Rosenzweig
Chapman University	General Physics	Eyal Amitai
Columbia University	Atmospheric Dynamics	Ron Miller
	Introduction to Atmospheric Science	Anthony Del Genio
Howard University	Lidar Special Topics	David Whiteman
Hunter College, City University of New York	Basic Concepts in Astronomy	Michael Way
Johns Hopkins University	Remote Sensing: Earth Observing Systems and Applications	K. Jon Ranson
University of Maryland Baltimore County	Atmospheric Physics II Remote Sensing of the Environment	Tamas Varnai (co-Instructor) Petya Entcheva Campbell
University of Wisconsin – Madison	Atmospheric Science and Geography	Mark Chandler

Post-Graduate Programs

The Division expects to maintain its support of post-graduate programs, which help foster new, innovative ideas for research. These programs include:

- **NASA Postdoctoral Program (NPP):** NPP is a program for postdoctoral fellows, run by the Oak Ridge Associated Universities (formerly run by the National Research Council). By carrying out research at NASA Centers, the Fellows contribute directly to the NASA mission while advancing their professional development. This program is funded by the Agency.

- **GSFC Visiting Fellows Program in the Earth Sciences:** This program has been organized by the GSFC Earth Sciences and Technology (GEST) Center and has been designed to attract professors on sabbatical leave and researchers at all levels of seniority within the Division. Selected through a competitive process, those chosen are typically pursuing independent research of their choice and have full access to NASA computing facilities and other resources at either the Greenbelt or the New York campus. See the following table for a list of Fellows.

Table B.5. GSFC Visiting Fellows Program in the Earth Sciences

Name	Institution	Research Plan	Relevant ESD Lab
FY 2010			
Wenge Ni-Meister *	Hunter College	Vegetation monitoring	614.4
De-Zheng Sun *	Cooperative Institute for Research in Environmental Science	Water vapor and clouds, ocean-atmosphere coupling, climate system and modeling	613.1
Chien Wang	Massachusetts Institute of Technology	Aerosols and precipitation	613.2
FY 2009			
Johannes Loschnigg	National Academy of Sciences	Environmental and science policy	610
FY 2008			
Manfredo Tabacniks *	Institute of Physics, University of Sao Paolo, Brazil	Instrumentation and measurements of aerosols	613.2
Ramesh Srivastava ^	University of Chicago	New radar development	613.1
Kurtulus Ozturk	Turkish Meteorological Service	Techniques in rain rate sensing	613.1
Nawo Eguchi *	National Institute for Environmental Studies (NIES), Japan	GEOS-5 assimilation techniques	610.1
Karen Mohr *	State University of New York, Albany, New York	Cloud resolving model development	613.1
Francois-Marie Breon	Laboratoire des sciences du climat et de l'environment	Aerosols	613.2
Jun Wang	University of Nebraska	Aerosol data assimilation in numerical models	613.2
FY 2007			
Pieternel Levelt *	KNMI, Holland	Broadening access and use of OMI data	613.3
Alexander Lipatov	University of Calgary	Modeling of magnetospheres/ heliosheaths of planets	610.6/673

* On sabbatical leave ^ Retired—Professor Emeritus

Table B.5. (continued) GSFC Visiting Fellows Program in the Earth Sciences

Name	Institution	Research Plan	Relevant ESD Lab
FY 2007 (continued)			
Michael Schulz *	Laboratoire des Sciences due Climate et de l'Environment, Gif-sur-Yvette, Franco	AEROCOM	613.2
Tad Anderson *	University of Washington	CALIPSO – A-Train integration of clouds and aerosol data	613.2
Nicholas Meskhidze *	Georgia Institute of Technology	Work on links between air pollution and ocean productivity	613.3
Raimund Muscheler	Lund University, Sweden	Sun-Earth connections	613.2
Qingyuan Zhang	University of New Hampshire	Remote sensing of photochemical active radiation in vegetation and gross primary productivity	614.4
FY 2006			
Martti Hallikainen *	Helsinki University	Polar climate change, specializing in microradiometry of snow and ice	614.6
Cynthia Randles	Princeton University	Biomass burning aerosols over Africa	613.2
Cuneyt Utku	George Washington University	L-band radiometry of the ocean and soil with application to Aquarius	614.6
FY 2005			
Zev Levin *	Tel Aviv University	Cloud-dust interactions	613
David Salstein	Atmos. & Environ. Research Inc.	Interactions of Earth rotation parameters with atmospheric dynamics	690
Toshiihiko Takemura	Research Institute for Applied Mechanics	Simulation of spectral radiation transport model results	613.3/613.2
FY 2004			
Warren Cohen *	Dept. of Agriculture Forest Service	Forest inventory/carbon	690
Carlos Garcia *	Univ. of Rio Grande, Brazil	Ocean color/primary production	614
Virginia Garcia *	Univ. of Rio Grande, Brazil	Ocean color/primary production	614
Marvin Geller *	State University of New York, Stony Brook	Atmosphere dynamics; stratosphere/mesosphere; climate	611
Maeng-Ki Kim *	Kongju National Univ., South Korea	Global circulation modeling	613
Roger Lang *	George Washington Univ., Washington, DC	Soil moisture measurements	614

* On sabbatical leave ^ Retired—Professor Emeritus

Table B.5. (continued) GSFC Visiting Fellows Program in the Earth Sciences

Name	Institution	Research Plan	Relevant ESD Lab
FY 2004 (continued)			
Robert Numrich *	Univ. of Minnesota, Minneapolis, MN	Climate model computing	606
Friedman Freund *	San Jose State Univ., San Jose, CA	Crustal Dynamics	690
Susanne Bauer	Lab. Science, Climate & Environ., Paris, France	Climate modeling/chemistry	611
Hyung Rae Kim	Ohio State Univ., Columbus, OH	Terrestrial physics	690
FY 2003			
Nadine Bell	Earth & Planetary Science, Harvard University	Chemical and dynamical processes in the atmosphere	611
William Chameides *	Earth & Atmos. Sci., Georgia Institute of Technology, Atlanta, GA	Coupling between atmospheric aerosols, climate, and carbon uptake by terrestrial ecosystems (National Academy of Sciences)	611
James A. Coakley *	Oceanic & Atmos. Sci., Oregon State Univ., Corvallis, OR	Cloud and aerosol retrievals to include an ensemble of aerosol-cloud interaction cases	613.2
Harshvardhan *	Earth & Atmos. Sci., Purdue Univ., West Lafayette, IN	Indirect cloud forcing by anthropengenic sulfate (Dept. Chair)	613.2/613.3
Dan Lubin *	Scripps Inst. of Oceanography, Univ. Cal., San Diego, La Jolla, CA	UV radiation at the surface and its effects on near surface biology	613.3
Michael E. Mann *	Environmental Sciences, Univ. of Virginia, Charlottesville, VA	Oceanic dynamical responses to atmospheric forcing of northern hemisphere ocean temperatures over the past 1000 years	611
Jacques Hinderer *	Univ. of Strasburg, Strasburg, France	Gravity measurements to validate/calibrate GRACE, use GRACE data for hydrological studies	697
Katherine Whaler *	Univ. of Edinburgh, Edinburgh, England	Modeling satellite magnetic data for the Earth and Mars	698
Wookap Choi *	Earth & Environ. Sciences, Seoul National Univ., Seoul, Korea	Stratospheric trace gas distributions, stratosphere-troposphere exchange, stratospheric cooling from CO_2	613.3

* On sabbatical leave ^ Retired—Professor Emeritus

Table B.5. (continued) GSFC Visiting Fellows Program in the Earth Sciences

Name	Institution	Research Plan	Relevant ESD Lab
FY 2003 (continued)			
Ken Minschwaner *	Geophys. Research Center, New Mexico Institute of Mining and Technology, Socorro, NM	Processes near the tropical tropopause responsible for transfer of mass and humidity from the troposphere to the stratosphere; studies of tropical cirrus cloud systems	613.3/613.2
Peter Colarco	Univ. of Colorado, Boulder, CO	Aerosol radiative properties using models, field and satellite measurements	613
David J. Lary	Chemical Informatics, Univ. of Cambridge, Cambridge, UK	Chemical Data Assimilation, produce a multi-annual analysis of chemical state of the atmosphere from UARS (Royal Society Fellow)	610.1

* On sabbatical leave ^ Retired—Professor Emeritus

Two-Year Colleges

Integrated Geospatial Education and Technology Training Project (iGETT): The iGETT project is helping to meet emerging workforce demands for geospatial technologists by enabling two-year colleges to expand existing Geographic Information System (GIS) programs to incorporate a wide range of remote sensing applications. The project was funded by the Advanced Technological Education Program, National Science Foundation in 2007, and will continue through 2011.

Forty community college and tribal college faculty members who currently teach GIS in a wide range of courses at two-year colleges enrolled in the project, one cohort in 2008 and another in 2009. Each group participated for a period of two years. The first year focused on geospatial tools training (i.e., remote sensing/GIS and data analysis software) and development of curriculum materials; the second on course enhancement, program development, student recruiting, and community engagement. Each faculty member wrote modules of his/her own through which students identify, download, analyze, and integrate Landsat, MODIS, and/or the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data with GIS to solve a specific workforce problem. Each module covers at least two weeks of class time and is publicly available on the iGETT Web site (see http://igett.delmar.edu).

The iGETT Web site also provides resources for all two-year college GIS instructors who are interested in replicating parts of the project or in using:

- Training materials provided for the iGETT participants.
- Curriculum materials developed by each participant.
- Outreach and marketing strategies implemented at the participating institution.

iGETT is co-led by ESD EPE staff in partnership with the National Council for Geographic Education, Del Mar College in Corpus Christi, TX, the Environmental Systems Research Institute, and the U.S. Geological Survey Land Remote Sensing Program.

The iGETT partnership and model are also being explored as a vehicle to develop geospatial technology training at the high school level, also in support of this developing area of the workforce. Members of the ESD EPE team are putting together a two-day meeting at GSFC that will bring together representatives of informal and formal education; industry and business; federal, state, and local government; and professional associations concerned with geospatial technology applications in the workforce, to explore effective means of reaching high school age youth with geospatial technology education and career awareness. The meeting is called, "Integrated Geospatial Education and Technology Training for High School Age Youth (HiGETT): Engaging Youth and Building the Workforce." Meeting outcomes will be disseminated widely through a report that conveys the richness of the discussion, details of the issues involved, and participants' shared recommendations on best means of moving forward.

Kindergarten to Grade 12 (K-12) Programs

Support of early education programs remains a priority to the Division. The ESD has produced educational materials and lesson plans for grades K-12, thereby contributing to the pipeline that will produce tomorrow's Earth scientists. The Division's scientists routinely present lectures and demonstrations to K-12 schools and youth groups to help develop an early interest in science. They also mentor students, and serve as judges at local science fairs. ESD scientists also mentor a number of high school students through individual initiatives and projects.

Mission-based education and engagement staff collaborate with the GSFC Education Office to deliver workshops for teachers during summer and to make classroom-based presentations. The Prince George's County Owens Science Center is a partner to develop and deliver NASA content on Science on a Sphere at the Visitor Center. Staff also partner with professional societies, colleges, other federal agencies to provide professional development for undergraduate students, and people already in the workforce. Finally, our staff also coordinate with the GSFC Education Office to develop and efficiently support new EPE programs with local/state level K-12 school partners (e.g., Howard, Frederick, Queen Anne's, and Anne Arundel Counties in Maryland) as well as international programs.

Following are a few examples of K-12 programs supported:

- **Educational GCM (EdGCM)**

  Global Climate Models (GCMs) are one of the primary tools used today in climate research. Unfortunately, few educators have access to GCMs, which have generally required significant computing facilities and skilled programmers. In collaboration with the National Science Foundation (NSF), NASA GISS has created EdGCM, software that allows teachers and students to run a state-of-the-art climate model on desktop computers. With EdGCM, one can explore the fundamentals of climate science using tools which are identical to those used in major climate research programs. Many simple climate experiments are possible (e.g., How does a changing Sun warm or cool the planet?), but, it is also possible to investigate current events as they are being studied by climate scientists. EdGCM comes with some prepared scenarios—for example, for global warming and ice ages—but teachers can also construct their own scenarios to satisfy curricular requirements. EdGCM allows teachers to produce their own instructional materials (text, charts, and images) and easily scales for use at levels from middle school to graduate school.

- **Practical Uses of Math And Science (PUMAS)**

  PUMAS is an online journal, a Web-based collection of brief examples aimed at giving K-12 teachers insights into how the math and science they teach are actually used in everyday life. This site was founded and is edited by Ralph Kahn (Climate and Radiation Branch). The examples are written primarily by scientists and engineers, and are available to teachers, students, and other interested parties via the PUMAS Web site (http://pumas.nasa.gov/). Scientists contribute their expertise by writing the examples, which may be activities, anecdotes, descriptions of "neat ideas," formal exercises, puzzles, or demonstrations. These examples are widely used by pre-college teachers around the world to enrich their presentation of topics in math and science. PUMAS offers researchers a way to make a substantial contribution to pre-college education with a relatively small investment of time and effort, and at the same time, to get a peer-reviewed science education journal article published on the Web. The National Science Teachers' Association recognized PUMAS by selecting it as a SciLinks site, and the National Council of Teachers of Mathematics has honored PUMAS with their

Illuminations award. Both awards emphasize the continuing use of PUMAS by teachers, a practical sort of recognition appropriate to the site itself.

Informal Education

- **Earth to Sky**

Earth to Sky is an ongoing and expanding partnership between NASA, the National Park Service (NPS), and the U.S. Fish and Wildlife Service (FWS), that enables informal educators to access and use relevant NASA science, data, and educational products in their work. Earth to Sky has produced a series of professional development workshops for informal educators, funded by NASA with in-kind contributions from LDCM, NPS, and FWS, most recently focusing on NASA's contributions to climate change science. Week-long workshops during which participants develop action plans are followed by a series of distance learning events to provide further science content and help establish a community of practice.

Earth to Sky workshops provide one-on-one interactions between NASA scientists, education and engagement staff, and NPS and FWS informal educators. A wealth of educational and science resources is delivered, and protected work time allows participants to develop plans for incorporating this content into their work. In this collegial atmosphere, presenters and participants share knowledge and experiences, building a community of practice. Opportunities are provided for continued involvement, through distance learning, regular communications, and participation in planning for future training events. Professional formative and summative evaluation helps the partnership maintain a high standard of quality.

As of March 2010, 130 participants have received training. These "alumni" have in turn trained over 1,800 other informal educators, tremendously increasing the reach of the program. As a direct result of Earth to Sky, thousands of school children and hundreds of thousands to millions of National Park visitors are receiving information on NASA's contribution to our understanding of Earth and space. One example is a park brochure on global climate change, featuring Landsat imagery. Over 400,000 of these have been printed and distributed to visitors in parks across the nation. Results indicate that through exhibits, handouts, public programming and a series of podcasts, the participants have reached over 2.8 million people with science-based climate change and other NASA Earth Science materials they learned at the workshop.

The partnership will conduct another workshop in 2010/2011, and develop a course on interpreting climate change for use at the National Conservation Training Center in 2011 and following years. A longitudinal evaluation effort aims to demonstrate the degree to which NASA content is used effectively in informal education settings in parks and refuges, and the extent to which a community of practice is established. Earth to Sky is co-led by ESD EPE staff in partnership with NPS, FWS, and University of California, Berkeley.

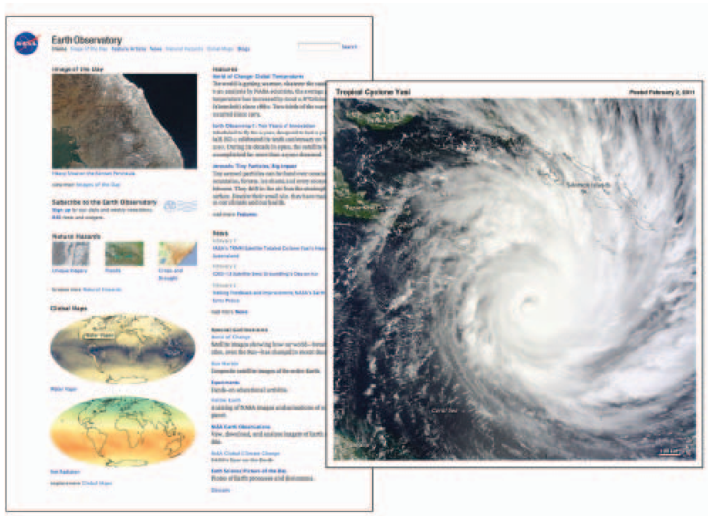
B.2) Public Engagement

- **Earth Observatory**

The Earth Observatory website (earthobservatory.nasa.gov) publishes NASA satellite imagery and scientific information about climate and environmental change (including natural hazards) and the use of space-based sensors for Earth science research and applications. Earth Observatory is, and continues to be, a flagship e-publication on Earth Sciences with a diverse and loyal audience, and a wide reach. There are more than 62,000 subscribers to its weekly newsletter, and the site receives more than 780,000 unique visitors each month on average. The primary target audience is the "science attentive" public although some content targets other audiences, including teachers, students, scientists, and public media. The site has won five Webby Awards in the "Science" and "Education" categories, as well as endorsements by Scientific American, Popular Science, TERC (an education research and development organization), the National Science Teachers Association, and many other organizations. The site's imagery and visualizations are routinely featured in National Geographic Magazine, CNN, The Guardian (UK), and many other mass media outlets. The site is funded by the EOS Project Science Office (PSO).

- **Continuing Mission EPE Activities via Senior Review Funding**

Senior Review proposals for post-prime mission continuation now include separate budgets for EPE activities. For the most recent Senior Review funding period, activities have included Earth & Sky podcasts, GSFC-produced vodcasts, content for museum distribution (Space Telescope Science Institute's ViewSpace program), Dynamic Planet content development, and a variety of other cross-mission efforts.



Example Earth Observatory home page (left), with inset of example Image of the Day from Feb. 2, 2011 of Cyclone Yasi approaching Queensland, Australia.

One such activity was the "Know Your Earth" video project with National CineMedia, developed with input from most missions involved in the recent Senior Review. "Know Your Earth" is a fun, engaging, and educational three-minute segment of "Did You Know?" questions that has a message focusing on global climate change and literacy, with distribution through the Lobby Entertainment Network (291 national movie theaters). "Know Your Earth" was shown during the summer movie blockbuster month of July 2010 (see www.nasa.gov/knowyourearth/).

- **NASA Earth Observations (NEO)**

NEO (neo.sci.gsfc.nasa.gov) is a web-based repository of imagery produced from global Earth science data sets. The target audiences are science centers, museums, formal and informal educators, science communicators, and citizen scientists (communities that desire high resolution Earth science imagery, but may not possess the expertise to acquire and manipulate the source data). NEO consists of a web-based browse interface, web services, and an ftp service to provide for a wide range of user access points. NEO contains over 50 data sets, many in daily, weekly, and monthly composites, and serves 50-100 GB of imagery monthly. The system is funded by the EOS PSO.

- **Visible Earth**

Visible Earth (visibleearth.nasa.gov) is a web-based repository of Earth science-related images, animations, and data visualizations from the Earth Observatory and other partners. The site currently holds about 21,000 records and all assets are stored at multiple resolutions. Since all of Visible Earth's assets are extensively indexed, the site lends itself particularly well to content syndication for NASA's communications partners (i.e., museums, formal education lesson developers, the mass media, etc.). Visible Earth receives an average of 200,000 unique visitors per month and serves approximately 850 GB in monthly image requests. The EOS PSO funds this site.

- **Climate Change Information Resource, New York Metropolitan Region (CCIR-NY)**

The CCIR-NY is an information resource for educators, policymakers, and the general public on the impacts of climate change and variability in the tri-state New York metropolitan area. This Web site provides scientific answers to basic questions about climate change, and how changes might impact New York City. While the site is specifically focused on the Big Apple, some lessons learned here apply to other urban areas. NASA provided the science used to answer basic and specific questions regarding climate change in the New York Metropolitan region. The site includes a series of questions relating to climate change and then answers them in a way accessible to a wide-ranging audience. It was developed under a grant from NOAA to the Center for International Earth Science Information Network, Columbia University, with the collaboration of NASA GISS and Hunter College (http://ccir.ciesin.columbia.edu/nyc/).

- **Printed Material**

  The EOS PSO produces a wide range of printed material about NASA-wide and GSFC ESD research programs and satellite missions. Specifically, they produce brochures, lithographs, posters, and fact sheets, as well as CDs and DVDs, about Earth science topics and EOS satellites. The EOS PSO funds most of these publications.

- **Conference Support and Organization**

  The EOS PSO also provides funding for general conference support and organization of NASA presence at numerous national and international scientific and educational conferences (e.g., American Geophysical Union [AGU], American Meteorological Society [AMS], IEEE International Geoscience and Remote Sensing Symposium [IGARSS], International Year of Chemistry Opening Ceremony, Odyssey of the Mind World Finals, etc.). As an example, the team played a leading role in organizing the NASA Science exhibition for the 2010 AGU Fall Meeting in San Francisco, CA. NASA Earth science showcased relevant satellite data on a nine-screen video wall or hyperwall, a robust tool capable of displaying multiple data visualizations and images simultaneously. In addition, a wide array of in-booth presentations brought large crowds to multiple sessions spread out over four days.

Example of EOS PSO outreach efforts over the past year. Clockwise from upper left: A-Train constellation graphic, SMAP mission poster (front and back), *Earth Observer* cover page, and AGU Fall 2010 exhibit with hyperwall display.

  Through the EOSPSO, NASA was invited to participate in the International Year of Chemistry Opening Ceremonies, held at the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Headquarters in Paris, France. Dr. Jack Kaye, Associate Director for Research for NASA's Earth Science Division, was invited by UNESCO to discuss the science behind studying atmospheric chemistry through remote sensing. Dr. Kaye was able to present a "guided narrative" of chemically-related data sets using the enhanced capabilities of the nine-screen hyperwall.

  The EOSPSO is also partnering with the Scientific Visualization Studio to develop new and exciting content for the hyperwall display. This partnership will enable scientists and outreach personnel to present exciting results using a state-of-the-art visualization tool.

- **Public Media**

  The ESD has adopted a two-pronged approach to communications with the public media. Our primary emphasis is on providing press releases and imagery to the NASA Public Affairs Office (PAO) through the efforts of the Earth Science News and Information Team. In an effort to proactively mine new story ideas, for the past five years, this team has been identifying and developing press releases for PAO. The team reached an all-time high in productivity over the last year and has had many of their stories play in major television and print media outlets. Our secondary emphasis has been to enable "direct to information consumer" communications via our Web sites and the NASA Portal.

- **Data Visualizations**

  The ESD supports the Scientific Visualization Studio (SVS), which is one of NASA's premier teams producing superior quality images, state-of-the-art animations, and data visualizations, all in support of a wide range of the ESD's communications and science activities, including NASA Public Affairs press releases, live presentations, various print publications, television, and video documentaries, etc. The SVS is also one of the principal areas for educators and students to obtain the most up-to-date and compelling NASA content for educational activities.

- **Science on a Sphere**

Science on a Sphere (SOS), originally developed by NOAA to enhance engagement, is a system which uses high-speed computers, video projectors, and advanced imaging techniques to project images onto a sphere to create the illusion of a planet, the Sun, a moon, or any other celestial body in space. In collaboration with the NOAA Environmental Technical Laboratory, the ESD has become a major contributor of content for SOS across the country, and has supported SOS installations across the country and at international venues. NASA Headquarters has recently asked that ESD develop and maintain a highly portable SOS system for its use at national and international conferences, with the plan to develop and field the portable SOS system at the upcoming World Radio Conference, next winter in Geneva.

Science on a Sphere is intended to help communicate science to the public, foster science education, and aid scientific visualization by providing a unique and engaging way of looking at the Earth in its "native format" rather than as a distorted flat representation. The latest in space-based Earth observations from imagery and/or data acquired by NASA's many Earth observing satellites are processed and formatted for display on the Sphere, and are provided to SOS systems in museums across the country. There is currently a Science on a Sphere in the GSFC Visitor Center. In 2009, the Science on a Sphere team recently traveled to Copenhagen, Denmark, to provide engagement and science support as an important component of the United States presence at the United Nations Climate Change Conference (COP15).

- **Dynamic Planet**

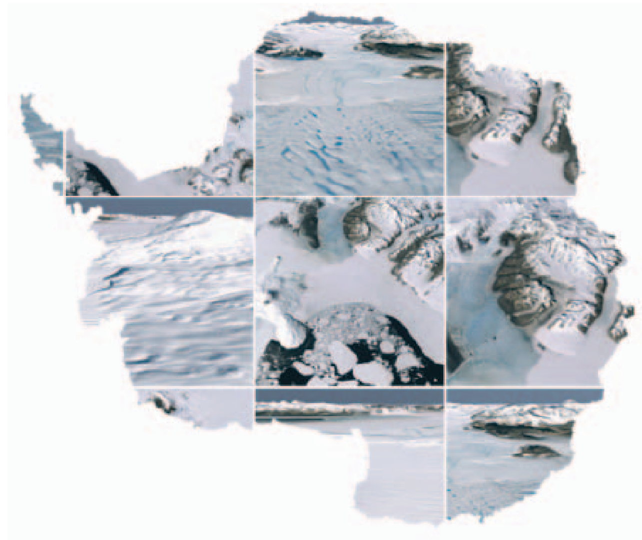
The Dynamic Planet provides the content and software interface to Global Imagination's Magic Planet digital video globe, allowing users to view and explore dynamic digital images of the Earth, other planets, and space. The ESD uses two Dynamic Planet configurations, a 24" diameter and a new 48" diameter "high-definition" globe, each with a NASA Science touch screen interface designed to allow users the opportunity to explore the changing planet. Highlights of the Dynamic Planet include its vital role in the United Nations Educational, Scientific, and Cultural Organization's (UNESCO) 34th General Conference (October 2007, Paris, France) and the opening ceremonies of UNESCO's International Year of Planet Earth (February 2008, Paris, France). Additionally, the Dynamic Planet served as a primary backdrop to President Obama on November 23, 2009, as he announced the Administration's new "Educate to Innovate" campaign from the Dwight D. Eisenhower Executive Office Building in Washington, DC.

- **The Electronic Theatre**

  The Electronic Theatre produces interactive, high-definition live presentations about Earth system science and NASA's remote sensing missions as an adjunct activity that leverages off the resources produced by the ESD's visualizations teams. This activity reaches thousands of live audience members each year.

- **The Landsat Image Mosaic of Antarctica (LIMA) Education Project**

  The NASA LIMA Education Project (lima.nasa.gov) is housed at the GSFC Hydrospheric and Biospheric Sciences Laboratory. In the format of an interactive website, it is designed as part of the International Polar Year to educate people about Antarctica through LIMA images, activities, visualizations, scientist interviews, and NASA's role in Antarctic research. Through the website's materials and particularly the "Antarctic Mysteries" section, students and educators can explore the continent.



Appendix C. Project Scientists and Deputy Project Scientists

Table C.1. Project Scientists and Deputy Project Scientists

Project	Project Scientist
Missions in Operation	
A-Train	Steven Platnick
Aqua	Claire Parkinson, Lazaros Oreopoulos (Deputy)
Aura	Anne Douglass, Bryan Duncan (Deputy for Science & Validation), Joanna Joiner (Deputy for Instruments, Tech., Outreach)
Earth Observing System (EOS)	Steven Platnick, David Starr (Validation Scientist), James Butler (Calibration Scientist)
Landsat 7	Jeffrey Masek, James Irons (Deputy)
New Millennium Program EO-1	Elizabeth Middleton, Bruce Cook (Deputy)
SeaWiFS	Chuck McClain, Stan Hooker (Deputy)
Solar Radiation and Climate Experiment (SORCE)	Robert Cahalan
Terra	Marc Imhoff, Si-Chee Tsay (Deputy), Robert Wolfe (Deputy for Data)
Tropical Rainfall Measuring System (TRMM)	Scott Braun, Erich Stocker (Deputy for Data Systems)

Table C.1. (continued) **Project Scientists and Deputy Project Scientists**

Project	Project Scientist
Missions in Formulation and Development	
Aquarius	David Le Vine (Deputy Mission PI)
CLARREO	Kurt Thome (Deputy)
DESDynI	Jon Ranson (Project Scientist for D-Lidar)
Glory	Michael Mishchenko, Ellsworth Welton (Deputy)
Geostationary Operational Environmental Satellite (GOES)	Dennis Chesters
Global Precipitation Measurement (GPM)	Arthur Hou, Gail Skofronick-Jackson (Deputy), Erich Stocker (Deputy for Data Systems)
ICESat II	Thorsten Markus, Thomas Neumann (Deputy), Matthew McGill (Instrument Scientist)
Joint Polar Satellite System (JPSS)	James Gleason (Program Scientist)
Landsat Data Continuity Mission (LDCM)	James Irons, Jeffrey Masek (Deputy)
NPOESS Preparatory Project (NPP)	James Gleason, James Butler (Deputy for Instruments and Calibration), N. Christina Hsu (Deputy for Algorithms)
Soil Moisture Active and Passive (SMAP)	Peggy O'Neill (Deputy)

Appendix D. Field Campaigns and Workshops

Table D.1 Field campaigns where scientists in the Division were Principal Investigators in FY 2010

Field Campaign	Principal Investigator
Climate Variability on the East Coast 2 (CliVEC 2), Climate Variability on the East Coast 3 (CliVEC 3), Climate Variability on the East Coast 4 (CliVEC 4)	Antonio Mannino
EcoDOM Campaign	Maria Tzortziou
Forest biomass measurements in support of NASA DBSAR, Wallops Flight Facility and surrounding area	Temilola Fatoyinbo
Genesis and Rapid Intensification Processes Experiment, Florida	Gerald Heymsfield
Hudson Valley marsh Investigations	Dorothy Peteet
Spectral dynamics in corn, associated with N cycling and phenology	Elizabeth Middleton
Tidal Marshes Field Campaign	Maria Tzortziou
Western Siberian Forest Measurement Campaign	K. Jon Ranson

Table D.2 Field campaigns where scientists in the Division were Co-Principal Investigators in FY 2010

Field Campaign	Co-Principal Investigator
Genesis and Rapid Intensification Processes Experiment, Florida	Scott Braun
Global Hawk Pacific (GloPac) environmental science mission	Paul Newman (Co-Project Scientist)
Paleoclimate Shocks: Environmental Variability, Human Vulnerability, and Societal Adaptation During the Last Millenium in the Greater Mekong Basin, Laos, Thailand	Benjamin Cook
Subglacial controls on Greenland Ice Sheet Marginal Acceleration, Western Greenland	Thomas Neumann

Table D.3. Field campaigns where scientists in the Division were Co-Investigators in FY 2010

Field Campaign	Co-Investigator
Australian Airborne Cal/val Experiment (AACES)	Edward Kim
CanEx – SM10 – Canadian Experiment Soil Moisture 2010, a joint SMOS/SMAP field experiment in Saskatchewan, Canada	Peggy O'Neill
Costa Rica Airborne Research and Technology Applications (CARTA) 2010	Geoff Bland
Frostburg Campaign	Maria Tzortziou
Global Hawk Pacific (GloPac) environmental science mission	Peter Colarco, Randy Kawa
GPM-Brazil Pre-CHUVA field campaign	Arthur Hou
GPM-CloudSat Light Precipitation Validation Experiment (LPVEx) in the Gulf of Finland	Arthur Hou
High Ice Water Content Experiment (HIWC)	Andrew Ackerman, Ann Fridlind
Measurements of Humidity and Validation Experiment, JPL/Table Mountain Facility, CA	David Whiteman
Midlatitude Continental Convective Clouds Experiment (MC3E)	Ann Fridlind
NASA LaRC B200 participation in the CALNex and CARES field campaigns	Brian Cairns
SMAPEx-1—first Australian SMAP Experiment in Yanco, NSW, Australia	Peggy O'Neill
Spectral dynamics in corn, associated with N cycling and phenology	K. Fred Huemmrich, Petya Entcheva Campbell, Yen-Ben Chieng, Qingyuan Zhang, Lawrence Corp
Western Siberian Forest Measurement Campaign	Ross Nelson

Table D.4. Workshops Convened by ESD Scientists in FY 2010

Workshop	Organizer
2nd VIIRS Land Team Validation Workshop, College Park, MD	Miguel Roman
4th GPM International Ground Validation Workshop hosted by the Finnish Meteorological Institute, Helsinki, Finland	Arthur Hou
5th Workshop of the International Precipitation Working Group, Hamburg, Germany	George Huffman, Christian Klepp
Air and Waste Management Association Workshop, Montreal, Canada and **Air and Waste Management Pre-Conference Course, Calgary, Canada**	Richard Kleidman
Aquarius Science Team Workshop	David Le Vine
A-Train Symposium, New Orleans, LA	Steven Platnick (co-Convenor)
California Air Resources Board Workshop, Sacramento, CA	Ana Prados and Richard Kleidman
Climate in a Box Workshop	Thomas Clune
Climate Sensitivity Extremes – Assessing the Risk	Dorothy Peteet (co-Convener)
Community Modeling and Analysis Group Workshop 2010, Chapel Hill, NC	Ana Prados
DESDynI Science Workshop, Greenbelt, MD	K. Jon Ranson
EdGCM: Global Climate Modeling for the Classroom, Lawrence Livermore National Lab	Mark Chandler
Forecasting phenology: Integrating Ecology, Climatology, and Phylogeny to Understand Plant Responses to Climate Change Working Group, National Center for Ecological Analysis and Synthesis	Benjamin Cook
GPM Radiometer Algorithm Workshop	Gail Skofronick Jackson
GRACE Hydrology Product Working Group Meeting, Austin, TX	Matthew Rodell
HyspIRI Science Symposium on Ecosystem Data Products, NASA/GSFC	Petya Entcheva Campbell
Microrad2010	David Le Vine (co-Chair)
MODIS Calibration Workshop	Xiaoxiong Xiong
MODIS Geophysical Products and Their Applications, Bangalore, India	Richard Kleidman, Shana Matoo
MODIS Science Team Meeting/Atmosphere Team breakout	Steven Platnick
NASA Climate Modeling and Data Applications Workshop (NASA-GCCE Project), Dickinson College, Carlisle, PA	Mark Chandler

Table D.4. (continued) Workshops Convened by ESD Scientists in FY 2010

Workshop	Organizer
NATO Advanced Study Institute on "Special Detection Technique (Polarimetry) and Remote Sensing, Kyiv, Ukraine	Michael Mishchenko
NDACC Raman Water Vapor Lidar Calibration Workshop, Greenbelt, MD	David Whiteman
Remote Sensing Workshop with Air Quality Applications, Sao Paulo, Brazil	Richard Kleidman, and Shana Matoo
Remote Sensing Workshop, Technion, Israel	Richard Kleidman, Robert Levy
Resilience and Adaptation to Climate Change Risks Workshop, Kennedy Space Center and the Space Coast, Cocoa Beach, FL	Cynthia Rosenzweig
Session IT41A, 2010 Ocean Sciences Meeting	Maria Tzortziou
Solar and Anthropogenic Influences on Earth: The Current Solar Minimum and Predictions for Future Decades, Keystone, CO	Robert Cahalan
The Agricultural Model Intercomparison and Improvement Project (AgMIP) Kickoff Workshop, Long Beach, CA	Alex Ruane, Cynthia Rosenzweig
Threats to Urban Forest Ecosystems with the Baltimore/Washington Partners for Forest Stewardship	Molly Brown (co-Convener)
UC Davis 2010 – Atmospheric Chemical Processes Pre-Conference Workshop, Davis, CA	Richard Kleidman, Ana Prados
UMBC Remote Sensing and Air Quality Workshop, Baltimore, MD	Ana Prados, Richard Kleidman
Workshop on Aerosol Observability, Monterey, CA	Peter Colarco (co-Convener)

Appendix E. Professional Activities, Honors, and Awards

Table E.1. Members of Academies

Academy	Name
National Academy of Engineering	Claire Parkinson
National Academy of Sciences	James Hansen

Table E.2. Fellows of Professional Societies

Society	Name
American Association for the Advancement of Science	Cynthia Rosenzweig, James A. Smith
American Geophysical Union	Anne Douglass, James Hansen, Randal Koster, William Lau, Charles McClain, Michael Mishchenko, Paul Newman, Compton Tucker, Warren Wiscombe
American Meteorological Society	Anne Douglass, Robert Cahalan, Anthony Del Genio, James Hansen, Randal Koster, William Lau, Michael Mishchenko, Claire Parkinson, Wei-Kuo Tao, Warren Wiscombe
American Philosophical Society	Claire Parkinson
American Society of Agronomy	Cynthia Rosenzweig
Institute of Electrical and Electronics Engineers	David Le Vine, James A. Smith
International Association of Geomagnetism and Aeronomy	Charles Jackman,
International Society for Optical Engineering (SPIE)	James A. Smith
Optical Society of America	Michael Mishchenko

Table E.3. ESD Scientists that are GSFC Senior Fellows

James Hansen
Claire Parkinson
James A. Smith
Compton Tucker

GSFC Senior Fellows form a very small group of individuals selected for their contributions to science, engineering, and technology.

Table E.4. Members of Committees of Professional Societies in FY 2010

Society	Committee Name	Member
American Association for the Advancement of Science	AAAS Council, Committee on Council Affairs	Claire Parkinson
American Geophysical Union	Fall Program Committee, Hydrology Section	Matthew Rodell
	Fellows Committee, Atmospheric Sciences Section	Michael Mishchenko
	Global Environmental Change Focus Group, Secretary	Molly Brown
	Hydrology Remote Sensing Technical Committee	Christa Peters-Lidard
	Hydrology Section Precipitation Technical Committee	Gail Skofronick-Jackson,
	Hydrology Section Precipitation Techniques Committee	Eyal Amitai Gail Skofronick-Jackson
	Journal of Advances in Modeling Earth Systems (JAMES) Advisory Board	Arthur Hou
	Meetings Committee	Kathy Fontaine
	Remote Sensing Technical Committee	Matthew Rodell
American Meteorological Society	AMS Annual Meeting Program Committee for Hydrology	Rolf Reichle
	Annual Meeting Oversight Committee	Christa Peters-Lidard
	Atmospheric Radiation Committee	Lazaros Oreopoulos
	Cloud Physics Committee	Ann Fridlind
	Council of the AMS	Anne Douglass
	Hydrology Committee	Rolf Reichle
American Society for Limnology and Oceanography	Meetings Committee	Maria Tzortziou
Association of American Geographers	Development Geographics Specialty Group, Secretary	Molly Brown
Department of Energy Atmospheric System Research Program	Cloud-Aerosol-Precipitation Interactions Steering Committee	Ann Fridlind
European Organization for the Exploitation of Meteorological Satellite	Satellite Applications Facility Evaluation Board	Arthur Hou
George Mason University	Department of Statistics Advisory Board Member	Ralph Kahn

Table E.4. (continued) Members of Committees of Professional Societies in FY 2010

Society	Committee Name	Member
Group on Earth Observations (GEO)	Human Health Task on Influenza	Richard Kiang
IEEE Computer Society, Accreditation Board for Engineering and Technology (ABET)	Computing Accreditation Commission, Executive Committee	James A. Smith
Institute of Electrical and Electronics Engineers (IEEE)	Administrative Committee, Geophysical and Remote Sensing Society, Fellows Committee	David Le Vine
International Society for Photogrammetry and Remote Sensing (ISPRS)	Commission VII Working Group on Human Health	Richard Kiang
International Committee on Space Research (COSPAR)	Commission A (Earth Science) Vice-Chair	Ralph Kahn
International Society for Remote Sensing of Environment	Technical Organizing Committee for International Society for Remote Sensing of Environment 34th Meeting	Marc Imhoff
International Union of Geodesy and Geophysics/International Association of Meteorology and Atmospheric Sciences (IUGG/IAMAS)	International Radiation Commission, President	Robert Cahalan
	Commission on Clouds and Precipitation, Secretary and Executive Member	David Starr
Montreal Protocol	Scientific Assessment Panel for the Montreal Protocol on Substances that Deplete the Ozone Layer, Co-Chair	Paul Newman
National Academy of Sciences, Commission F	Committee for the International Union of Radio Science	James A. Smith
National Center for Atmospheric Research	Community Advisory Board	Gavin Schmidt
National Research Council	Deep-Time Climate Change Committee	Mark Chandler
	Study Committee on Climate Predictability on Intraseasonal-to-Interannual Timescales	Randal Koster
Paleoclimate Scientists	“Neotoma” Planning	Dorothy Peteet
World Climate Research Program	International Panel of the Global Land Atmosphere System Study (GLASS) of the Global Energy and Water Cycle Experiment	Rolf Reichle
World Climate Research Program/International Geosphere/Biosphere Program	Aerosols, Clouds, Precipitation, Climate Program Scientific Committee	Ann Fridlind
World Climate Research Program, Climate Variability and Predictability (CLIVAR)	Past Global Changes (PAGES)/CLIVAR Intersection Panel, Co-Chair	Gavin Schmidt

Table E.5. Editorships of Professional Journals in FY 2010

Journal	Editor
Geospatial Health (editorial board)	Richard Kiang
Journal of Climate	Anthony Del Genio
Journal of Quantitative Spectroscopy and Radiative Transfer	Michael Mishchenko

Table E.6. Associate Editorships of Professional Journals in FY 2010

Journal	Associate Editor
Advances in Adaptive Data Analysis	Steven Long (Assistant Editor)
Annals of Glaciology	Thorsten Markus
Atmospheric Measurement Techniques	Joanna Joiner (Executive Editor), Pawan K. Bhartia
Climatic Change	Cynthia Rosenzweig
IEEE Geoscience and Remote Sensing Letters	Edward Kim
IEEE Transactions Geoscience and Remote Sensing	James. A. Smith, Thorsten Markus
Journal of Applied Remote Sensing	Xiaoxiong Xiong
Journal of Atmospheric Sciences	Scott Braun
Journal of Climate	Gavin Schmidt
Journal of Earth Science and Climatic Change	Molly Brown
Journal of Geophysical Research—Atmospheres	Steven Platnick, Robert Levy
Journal of Geophysical Research—Biogeosciences	Jim Collatz
Journal of Glaciology	Wei Li Wang (Scientific Editor)
Journal of Hydrometeorology	George Huffman, Michael Bosilovich
Kinematics and Physics of Celestial Bodies and **Waves in Random and Complex Media**	Michael Mishchenko (Editorial Board Member)

Table E.7. Editors of Special Issues in FY 2010

Name of Special Issue	Editor
200th Issue of the Journal of Glaciology	Wei Li Wang (Scientific Editor)
50 Years of JQSRT, Journal of Quantitative Spectroscopy and Radiative Transfer	Michael Mishchenko
IEEE Transactions on Geoscience and Remote Sensing Special Issue for Microrad 2010	David Le Vine (Associate Editor)
IEEE Transactions on Geoscience and Remote Sensing Special Issue on Calibration and Validation of ALOS Sensors (PALSAR, AVNIR-2, and PRISM) and Their Use for Bio- and Geophysical Parameter Retrievals	James A. Smith
Silvilaser 2009 Special Issue, Photogrammetric Engineering and Remote Sensing	Ross Nelson (co-Editor)
TRMM Diabatic Heating, Journal of Climate	Anthony Del Genio

Table E.8. List of GSFC Awards Received in CY 2010

GSFC Award	Recipient
Exceptional Achievement for Outreach	Steve Graham (Wyle)
Exceptional Achievement for Outreach (group)	Scientific Visualization Studio
Exceptional Achievement for Science	Bryan Duncan
Exceptional Achievement for Science (group)	MERRA Team

Table E.9. List of NASA Honor Awards Received in CY 2010

NASA Award	Recipient
Exceptional Achievement Medal	Diana Elben
Exceptional Service Medal	Jay Herman
Group Achievement Award	MERRA Team
Outstanding Leadership Medal	Marc Imhoff

Table E.10. List of National and International Honors and Awards Received in CY2010

National and/or International Awards	Recipient
2010 Blue Planet Prize	James Hansen
2010 Co-Recipients of the Federal Laboratory Consortium for Technology Transfer's (FLC) Interagency Partnership Award	Compton Tucker, Assaf Anyamba (UMD), Jennifer Small (SSAI), Edwin Pak (SSAI)
American Meteorological Society Remote Sensing Prize	Claire Parkinson
Membership in the American Philosophical Society	Claire Parkinson
NOAA's David Johnson Award	Molly Brown
Sigma Xi Distinguished Lecturer—2010	Marc Imhoff
Sophie Prize 2010	James Hansen
U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Superior Effort Technology Transfer Award	Compton Tucker, Assaf Anyamba (UMD), Jennifer Small (SSAI), Edwin Pak (SSAI)
William T. Pecora Award	Forrest Hall (UMBC)

Appendix F. Acronyms

D-Winds	Three-Dimensional Tropospheric Winds from Space-based Lidar
4D-var	4 dimensional variational
AAAS	American Association for the Advancement of Science
AACES	Australian Airborne Cal/val Experiment
AAMP	Auroral Acceleration Multiprobe
ABET	Accreditation Board for Engineering and Technology
ACAM	Airborne Compact Atmospheric Mapper
ACDB	Atmospheric Chemistry and Dynamics Branch
ACE	Aerosol-Cloud-Ecosystem mission
ACE	Aerosol Characterization Experiments
ACM SIGGRAPH	Association for Computing Machinery Special Interest Group on Graphics and Interactive Techniques
ACT	Advanced Component Technology
ADAM	Aeronomy and Dynamics at Mars
AeroCenter	GSFC Center of Excellence in Aerosol Research
AERONET	AERosol RObotic NETwork
AESMIR	Airborne Earth Sciences Microwave Imaging Radiometer
AGCM	Atmospheric General Circulation Model
AgMIP	The Agricultural Model Intercomparison and Improvement Project
AGU	American Geophysical Union
AIM	Aeronomy of Ice in the Mesosphere
AIRS	Atmospheric Infrared Sounder
AITT	Airborne Instrument Technology Transition
ALVICE	Atmospheric Lidar for Validation, Interagency Collaboration and Education
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer-Earth Observation System
AMSU	Advanced Microwave Sounding Unit
APEC	Asia-Pacific Economic Cooperation
APS	Aerosol Polarimetry Sensor
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ASPRS	American Society of Photogrammetry and Remote Sensing

ASR	Atmospheric Systems Research
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTG	Advanced Software Technology Group
ATIP	Advanced Technology Initiatives Program
ATL	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
A-Train	Afternoon Satellite Constellation
ATTREX	Airborne Tropical TRopopause Experiment
AVDC	Aura Validation Data Center
AVHRR	Advanced Very High Resolution Radiometer
AWC	Atmospheric Water Cycle
B&P	Bid and Proposal
BRDF	Bidirectional Reflectance Distribution Function
BrO	Bromine Monoxide
BUV	backscatter ultraviolet
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAR	Cloud Absorption Radiometer
CARB	California Air Resources Board
CARPE	Central African Regional Program for the Environment
CBLAST	Coupled Boundary Layers Air/Sea Transfer
CCIR-NY	Climate Change Information Resource, New York
CCM	Chemistry Climate Model
CCMC	Community Coordinated Modeling Center
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science Plan
CDC	Center for Disease Control
CEAS	Center for Earth-Atmospheric Studies
CERES	Clouds and the Earth's Radiant Energy System
CHOCHO	Glyoxal
CIMSS	Cooperative Institute of Meteorological Satellite Studies
CISTO	Computational and Information Science and Technology Office
CLAIM-3D	3D Cloud-Aerosol Interaction Mission
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLIVAR	WCRP project on International Research Program on Climate Variability and Predictability
CliVEC	Climate Variability on the East Coast
CLM	Community Land Model
CLPP	Cold Land Processes Pathfinder
CLPX	Cold Land Processes Experiment
CM&O	Center Management and Operation
CO	Carbon Monoxide
CO_2	Carbon Dioxide

COMMIT	Chemical Optical and Microphysical Measurements of In-Situ Troposphere
CoSMIR	Conically Scanning Millimeter-wave Imaging Radiometer
COSPAR	Committee on Space Research
CoSSIR	Conical Scanning Submillimeter-wave Imaging Radiometer
CPL	Cloud Physics Lidar
CPU	Central Processing Unit
CrIS	Crosstrack Infrared Sounder
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
CSU	Colorado State University
CTM	Chemical Transport Model
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office
DAS	Data Assimilation System
DDF	Director's Discretionary Fund
DESDynI	Deformation, Ecosystem Structure, and Dynamics of Ice
DISC	Data and Information Services Centers
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DOE	Department of Energy
DWSS	Defense Weather Satellite System
ECMWF	European Center for Medium-range Weather Forecasting
ECOSAR	Ecological Structure Activity Relationships
EDC	Eros Data Center
EdGCM	Educational Global Climate Models
EDOP	ER-2 Doppler radar
EnKF	Ensemble Kalman Filter
ENSO	El Niño/Southern Oscillations
ENVISAT	ENVIronment SATellite
EO-1	Earth Observing-1
EOS	Earth Observing System
EOSDIS	Earth Observing System (EOS) Data and Information System
EP TOMS	Earth Probe Total Ozone Mapping Spectrometer
EPA	Environmental Protection Agency
EPE	Education and Public Engagement
EPRI	Electric Power Research Institute
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
EROS	Earth Resources Observation and Science
ERS	European Remote Sensing
ES LOB	Earth Science Line of Business
ESA	European Space Agency
ESD	Earth Sciences Division

ESDIS	Earth Science Data and Information System
ESMF	Earth System Modeling Framework
ESMs	Earth System Models
ESPD	Earth Science Projects Division
ESSIC	Earth System Science Interdisciplinary Center
ESSP	Earth System Science Pathfinder
EUV	extreme ultraviolet
EV	Earth Venture
FAO	United Nations Food and Agriculture Organization
FAS	Foreign Agriculture Service
FCA	Full Cost Accounting
FTE	Full Time Equivalent
FWS	Fish and Wildlife Service
GACM	Global Atmospheric Composition Mission
GACP	Global Aerosol Climatology Project
GCDC	Global Change Data Center
GCE	GSFC Cumulus Ensemble
GCMD	Global Change Master Directory
GCMs	General Circulation Models
GCOM-W	Global Change Observation Mission-Water
GCSS	Global Energy and Water Cycle Experiment's Cloud System Study
GEIS	Global Emerging Infections Surveillance and Response Program
GEO	Geosynchronous/Geostationary Earth Orbit
GEO	Group on Earth Observations
GEOCAPE	Geostationary Coastal and Air Pollution Events
GEOS	GSFC Earth Observing System
GEOS CCM	Global Earth Observing System Chemistry Climate Model
GEOSS	Global Earth Observation System of Systems
GES	GSFC Earth Science
GES	GSFC Earth Sciences
GEST	GSFC Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFO	GeoSat Follow-On
GHG	Greenhouse Gases
GHRSST	Global High Resolution Sea Surface Temperature
GIC	Ground Induced Current
GIS	Geographic Information System
GISS	GSFC Institute for Space Sciences
GLACE	Global Land-Atmosphere Coupling Experiment
GLAS	Geoscience Laser Altimeter System
GLASS	Global Land Atmosphere System Study
GLDAS	Global Land Data Assimilation System

GLOBE	Global Learning and Observations to Benefit the Environment
GloPac	Global Hawk Pacific experiment
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GOCART	GSFC Global Ozone Chemistry Aerosol and Radiation Transport
GOES	Geostationary Operational Environmental Satellite
GoHFAS	GSFC Howard University Fellowship in Atmospheric Sciences
GOME	Global Ozone Monitoring Experiment
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
G-PUCCINI	GISS model for Physical Understanding of Composition-Climate Interactions and Impacts
GRACE	Gravity Recovery and Climate Experiment
GRIP	Genesis and Rapid Intensification Processes
GSFC	GSFC Space Flight Center
GSI	Grid-point Statistical Interpolation
H_2O	Water
HALOE	Halogen Occultation Experiment
HCHO	Formaldehyde
HIRS	High Resolution Infrared Sounder
HIWRAP	High-altitude Imaging Wind and Rain Airborne Profiler
HOMER	High-Output, Maximum Efficiency Resonator
HS3	Severe Storm Sentinel Mission
HU	Howard University
HyspIRI	Hyperspectral/IR Imager
IAMAS	International Association of Meteorology and Atmospheric Sciences
ICESat	Ice, Cloud, and Land Elevation Satellite
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IESA	Integrated Earth System Analysis
IGARSS	Institute of Electrical and Electronics Engineers, Inc. (IEEE) Geoscience and Remote Sensing Society
iGETT	Integrated Geospatial Education and Technology Training Project
IIP	Instrument Incubator Program
InSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
IPP	Innovative Partnerships Program
IPY	International Polar Year
IR	Infrared
IRAD	Internal Research and Development
ISCCP	International Satellite Cloud Climatology Project
ISPRS	International Society for Photogrammetry and Remote Sensing
ISS	International Space Station
IT	Information Technology

IUGG	International Union of Geodesy and Geophysics
JAMEX	ACE-Asia, Joint Aerosol Monsoon Experiment
JAXA	Japan Aerospace Exploration Agency
JCES	Joint Center for Earth Science
JCET	Joint Center for Earth Systems Technology
JCSDA	Joint Center for Satellite Data Assimilation
JIESIC	Joint Interdisciplinary Earth Science Information Center
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
K-12	Kindergarten to Grade 12
LAADS	MODIS L1 and Atmospheres Archive and Distribution System
LANCE	Land Atmosphere Near Real Time capability for Earth Observing Systems
LaRC	Langley Research Center
LASCO/SOHO	Large Angle Spectrometric Coronograph/Solar Heliospheric Observatory
LASP	Laboratory for Atmospheric and Space Physics
LDAS	Land Data Assimilation System
LDCM	Landsat Data Continuity Mission
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LEO	Low Earth Orbit
LIS	Land Information System
LIS	Lightning Imaging Sensor
LIST	Lidar Surface Topography
LOB	Line of Business
LPSO	Landsat Project Science Office
LPVEx	Light Precipitation Validation Experiment
LTDR	Long Term Data Record
MAG/ACE	Magnetometer/Advanced Composition Explorer
MAS	MODIS Airborne Simulator
MC	Magnetospheric Constellation (MagCon)
MENA	Middle East and North Africa
MERRA	Modern Era Retrospective-Analysis for Research and Applications
MESSENGER	MErcury Surface, Space ENvironment, GEeochemistry, and Ranging
MIS	microwave imaging/sounding
MISR	Multi-angle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MODAPS	Moderate Resolution Imaging Spectro-radiometer (MODIS) Data Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Orbiter Laser Altimeter
MOS	Modular Optoelectronic Scanner
MPLNET	Micropulse Lidar Network
MU-SPIN	Minority University-SPace Interdisciplinary Network
NAO	North Atlantic Oscillation

NAS	NASA Advanced Supercomputing
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBO	New Business Office
NBRP	New Business Review Panel
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Computational Sciences
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDACC	Network for the Detection of Atmospheric Chemical Change
NEO	NASA Earth Observations
NESDIS	National Environmental Satellite Data and Information Service
NIP	Normal Incidence Pyrheliometers
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOBM	NASA Ocean Biogeochemistry Model
NOO	New Opportunities Office
NOVICE	Newly-Operating and Validated Instruments Comparison Experiments
NPOESS	National Polar-orbiting Operational Environmental Satellite System
N-POL	NASA Polarization radar
NPP	NASA Postdoctoral Program
NPP	NPOESS Preparatory Project
NPS	National Park Service
NRA	NASA Research Announcement
NRC	National Research Council
NRL	Naval Research Laboratory
NRT	Near Real Time
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSIPP	NASA Seasonal to Interannual Prediction Project
NSTA	National Science Teachers Association
NWP	Numerical Weather Prediction
O_3	Ozone
OCDSPS	Ocean Color/SST Data Processing System
OCEaNS	Ocean Carbon Ecosystems and Near-Shore
OCTS	Ocean Color and Thermal Scanner
ODS	Ozone Depleting Substance
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
ORCA	Ocean Remote Chemical/optical Analyzer
OSEs	Observing System Experiments
OSSEs	Observing System Simulation Experiments

PACE	Pre- Aerosol-Cloud-Ecosystem mission
PAGES	Past Global Changes
PAO	Public Affairs Office
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PATH	Precipitation and All-weather Temperature and Humidity
PEATE	Product Evaluation and Algorithm Test Element
PECASE	Presidential Early Career Award for Scientists and Engineers
PEEC	Public Engagement and Education Council
PI	Principal Investigator
PMM	Precipitation Measuring Missions
POAM	Polar Ozone and Aerosol Measurement
POES	Polar Operational Environmental Satellite
POETRY	Public Outreach, Education, Teaching, and Reaching Youth
POLDER	POLarization and Directionality of the Earth's Reflectance
PPS	Precipitation Processing System
PSP	Precision Spectral Pyranometers
PUMAS	Practical Uses of Math And Science
QWIPS	Quantum Well Infrared Photodectors
R&A	Research and Analysis
RCMRD	Regional Center for Mapping for Resource Development
RDMS	Research and Development Multiple Support
ROSES	Research Opportunities in Space and Earth Sciences
RRAP	Resident Research Associateship Program
RRS	Rapid Response System
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric ChartographY
SCLP	Snow and Cold Land Processes
SDPS	Sea-viewing Wide Field of view Sensor (SeaWiFS) Data Processing System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SED	Sciences and Exploration Directorate
SEPOF	Science Education and Public Outreach
SERVIR	Spanish for "to serve"
SHADOZ	Southern Hemisphere Additional Ozonesondes
SIESIP	Seasonal to Interannual Earth Science Information and Partners
SIMBIOS	Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies
SIR-C	Spaceborne Imaging Radar
SIRICE	Submillimeter and Infrared Ice Cloud Experiment
SIVO	Software Integration and Visualization Office

SMAP	Soil Moisture Active Passive
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SMD	Science Mission Directorate
SMM/I	Special Sensor Microwave/Imager
SMMR	Scanning Multichannel Microwave Radiometer
SNR	Signal to Noise Ratio
SO_2	Sulfur Oxides
SOHO	Solar and Heliospheric Observatory
SORCE	Solar Radiation and Climate Experiment
SOS	Science on a Sphere
SPIE	International Society for Optical Engineering
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SSBUV	Shuttle Solar Backscatter Ultraviolet
SST	Sea Surface Temperature
STROZ-LITE	Stratospheric Ozone Lidar Trailer Experiment
SUNBEAMS	Students United with NASA Becoming Enthusiastic About Math and Science
SVS	Scientific Visualization Studio
SWBs	Solar Weather Buoys
SWE	Snow Water Equivalent
SWEPAM/ACE	Solar Wind Electron, Proton and Alpha Monitor/Advanced Composition Explorer
SWOT	Surface Water and Ocean Topography
TC^4	Tropical Composition, Cloud, and Climate Coupling Experiment
TCSP	Tropical Cloud Systems and Processes
TES	Troposphere Emission Spectrometer
THORPEX	The Observing System Research and Predictability Experiment
TIROS	Television Infrared Observation Satellites
TIRS	Thermal Infrared Sensor
TMI	TRMM Microwave Imager
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean TOPography EXperiment
TOVS	NOAA's TIROS Operational Vertical Sounder
TRF	Total Solar Irradiance (TSI) Radiometer Facility
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TSDIS	Tropical Rainfall Measuring Mission (TRMM) Science Data and Information System
TSI	Total Solar Irradiance
TSIS	Total Solar Irradiance Sensor
TTL	tropical tropopause transition layer
TWC	Terrestrial Water Cycle
UARS	Upper Atmosphere Research Satellite

UAS	Unmanned Aircraft System
UMBC	University of Maryland at Baltimore County
UMCP	University of Maryland at College Park
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change
UNH	University of New Hampshire
US GEO	U.S. Group on Earth Observations
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
UV	Ultraviolet
UV-B	Ultraviolet-B
UW	University of Wisconsin
VAL	Visualizations Analysis Laboratory
VCL	Vegetation Canopy Lidar
VEG	Vegetation
VIC	Variable Infiltration Capacity model
VIIRS	Visible Infrared Imager Radiometer Suite
VIRS	Visible and Infrared Scanner
VIS IR	Visible Infrared
VITAL	Visual and Technical Arts Lab
WCRP	World Climate Research Program
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WWRP	World Weather Research Programme